Simplified Matlab Calculation tool for LCA optimization of Domestic Buildings

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Table of Contents

Table of Contents

Table of Contents

Table of Contents

Table of Contents

Table of Contents

Table of Contents

List of figures

List of figures

List of figures

List of tables

List of tables

List of tables

List of tables

Abstract

Sustainability approach within the construction sectors is a very complex task. These sectors are responsible for between 20% and 40% of energy consumptions of developed countries. It is agreed as one of the most important sectors that should urgently change its way of production to reduce the environmental impact caused.

Life Cycle Assessment (LCA) has been used to study the environmental impacts of different products and systems since the early ´70s. When the evaluated product is a complete building, these assessments become a great source of information with which governments and councils are able to demonstrate their fight and effort to get better and more sustainable cities. Although there are several tools to study the energy efficiency and environmental impacts of buildings the most common ones are complex software. Several issues arise when performing simplified LCA, such as the great amount of data involved, different units, scenarios and assumptions that a building could offer resulting on a wide range of cases and combinations.

Despite having access to this knowledge, a complete LCA does not become an easy task within the domestic sector where a all stages and several factors, such as economic and social, could be considered.

Construction stakeholders must develop a deeper understanding of how buildings perform at every stage within their life span in terms of environmental impact and energy consumption. This is the only way to implement measures that improve their sustainability and the circular economy. , as we move closer to the agreed 2030 and 2050 goals.

This research presents a possible solution with a simplified methodology for LCA optimization for domestic buildings using a user-friendly tool based on Matlab software, having accurate complete evaluations within minutes with insulation optimization options and comparison between different scenarios.

Keywords: Matlab, Life Cycle Assessment, LCA, Sustainability, user-friendly tool.

List of abbreviations

ADP	Abiotic Resource Depletion
AP	Acidification Potential of land and water
BBLC	Beyond the Building Life Cycle
BIM	Building Information Modelling
BMQ	Building Material Quantities
BR	Building Regulations
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Methodology
CEN	French: "*Comite Européen de Normalisation*" (European Committee for Standardisation)
EC	Embodied Carbon
EE	Embodied Energy
EMS	Energy Minimum Standards
ENV	Environmental
EP	Eutrophication Potential
FE	Final Energy
GHA	Glasgow housing Association
GHG	Green House Gas
GWP	Global Warming Potential
IAM	Impact Assessment Method
ICE	Inventory of Carbon and Energy (database)
IES	Integrated Environmental Solutions (software)
ISO	International Standardisation Organization
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LCI	Life Cycle Inventory
LCIA	Life Cycle Inventory Analysis
LED-E	List of Environmental Data of construction Elements
LED-M	List of Environmental Data of construction Materials
MJ	Mega Joule
NZC	Net Zero Carbon
NRPE	Non-renewable Primary Energy
ODP	Depletion Potential of the stratospheric ozone layer
POCP	Formation Potential of Photochemical Oxidants
ReqSL	Required Service Life (it could also appear as RSL).

List of abbreviations

RSP	Reference Study Period
SLCA	Simplified Life Cycle Assessment
SLR	Servile Life Required
SQM	Square metre (m^2)
TC	Technical Committee
TTW	Tank to Wheel (Embodied Energy Fuel loads)
UK	United Kingdom
UN	United Nations
WTW	Well to Tank (Embodied Energy Fuel loads)
WWT	Well to Wheel (Embodied Energy Fuel loads)

1

CHAPTER 1: INTRODUCTION

1.1. Overall aim of this thesis

This PhD research aims to establish a holistic LCA method rather than specific building elements evaluation method. The aim is to achieve a simplified, yet accurate, approach to the LCA of domestic projects. This goal involves important criteria that are not currently widely considered within existing LCA methos, such as an accurate end-of-life process and beyond that stage. For those calculation, current tools do not reflect the same the level of detail as per other earlier building stages such as manufacturing or operational phases.

The legal framework in which this thesis falls includes international standards about energy and environmental impacts as well as sustainable management [1-3]. These standards also define a framework for social and economic factors, despite those are not part of the scope of this thesis. This legal framework will be explained in more detail in the relevant chapter of this thesis.

1.1.1. Scope of the thesis

As described above, this project focuses on the simplification process and user-friendly approach to LCA of domestic projects. The location context is the UK, leaving out of the scope other international domestic building typologies and construction methods.

The following subjects are *not* part of the scope of this research:

- The application of social and economic factors within the calculation of LCA of domestic buildings [4].
- Quality verification methods regarding environmental impacts of construction materials.
- Detailed energy modelling calculation for the operational stage of buildings.
- In-depth analysis of potential saving from impacts occurred after the end-of-waste line of construction materials.
- Wastage routes for construction materials outside the UK.
- Environmental impacts from furniture, manpower, facilities and transportation due to these factors.
- In-depth analysis of environmental impacts allocation within environmental categories and indicators for construction materials or processes.

The reasons for excluding these areas from the scope of this project are addressed as they arise throughout the thesis.

1.2. Global Context

1.2.1.   Limits of Growth

Many authors argue that the world population will increase from 6,500 million in 2005 to 9,100 million in 2050 [5]. If current trends continue, urban areas will increase by double their population in a period of 45 years and infrastructure will have to be built to cope. Carbon footprints also increase as the built environment will pollute and use energy and materials potentially negatively off-set many of the gains made in 1990 [6]. In addition, the countries that have decided to start mitigating their excessive consumption of resources, based on future predictions made according to their trajectory in recent years, have already begun to explore new energy sources and policies [7].

1.2.2.   Construction sector

As a result of this growth the contribution to those figures of the built environment will be greater. The construction sector is also the Europe's largest industrial employer, accounting for 7.3 % of total EU employment. It generates about 9 % of Gross Domestic Product providing 18 million direct jobs [8].

Furthermore, the energy consumption of this sector accounts for the 23% of the total industrial activities in developed countries [9]. Its resources demand is about the 44% of the total raw materials consumption and about 32% of the total CO_2 emissions [10].

Construction is therefore a key sector in European national economies, society and environmental aspects [9]. Hence, it is worth researching and developing new methods in order to reduce this energy consumption and CO_2 emissions within the built environment. This will affect to a wide range of industrial partners and could drive to a major impact in national legislation and economies.
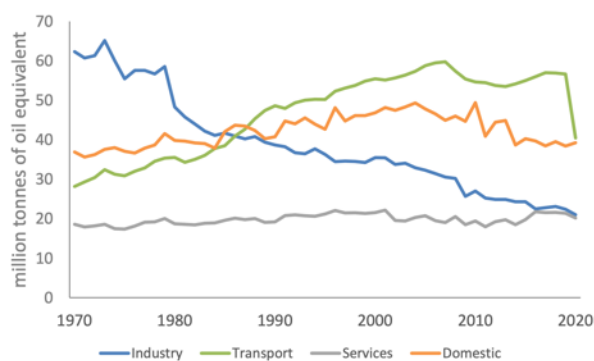
Figure 1.1: UK energy consumption by sectors

1.2.3.   Domestic sector

When approaching the construction industry figures, it is seen that the domestic sector is responsible of the 29% of the total in terms of energy consumption within the UK. It is one of the greatest contributors to environmental impact only behind the Transport sector which accounts for the largest proportion up to 40% [11].

In addition, since 2014, the domestic sector saw the biggest increase in both absolute and percentage terms for the overall final energy consumption, within the last year, when accounting for main stream sectors in the UK [11].

The number of households in the UK has grown since 1970 in a proportion of 46%. Population has also grown but at a lower rate, resulting in a reduction of residents per household. Due to this fact energy demand should decrease per unit although high number of them and continuous increasing prices of gas and electricity result in higher energy demand globally [11].

Within this domestic sector, local authority and housing association dwellings, also known as social housing buildings, account for almost the 18% of the total in the UK, often coinciding with lower incomes families and areas with fuel poverty trends [12].

Having this context, where gas and electricity prices are raising globally, one of the questions that arises is how to reduce energy demand and GHG emissions for housing developments over their complete life cycle in order to reduce costs and environmental impacts. Solving this question would help to reduce the overall built environment impacts, specially the domestic sector.

1.2.4.   Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) has been used to study the environmental impacts of different products and systems since the early 1970s. It started as a tool to minimise waste for manufacturing small products but then energy and CO_2 emissions figures within that process was an optional addition [13].

Although there are several international tools to study and evaluate the energy efficiency and environmental impact of buildings the most common programs involve the use of complex software [4]. These software packages should be able to evaluate different forms of construction from the design stage to the end of use stage to choose the most sustainable option.

It is important that Architects [14], mainly, but also other stakeholders develop an understanding of how buildings perform during every stage within their life span including design, construction, operational use and end-of-life in order to accurately be aware of the environmental impact and circularity potential [15] for current and future built environment within Europe and all around the world.

LCA programs should be equally applicable to renovation and refurbishment projects. It is extremely important that accurate information to assess the renovation of existing buildings and compare long term costs with potential new build alternatives were provided [16]. Urban regeneration is a complex matter and Local Authorities, Housing Associations etc all need to weigh up all the costs (social, economic and environmental) of demolishing and rebuilding a new community against the opportunity to refurbish dwellings to XXI century standards. LCA tools help in these decision-making processes. Annual European growth rates in the residential sector are around 1% [8], this means that there will need to be a significant volume of renovation and refurbishment projects in the coming decades in order to achieve the stringent 2050 CO_2 targets [17]. Therefore, accurate tools and methodologies would need to be developed to assist in decision-making processes that best support the built environment for the millions of people living old building stock across developed countries.

1.3. Challenges in interpreting LCA data

There is a clear low link between the environmental assessment tools models and real-life monitoring figures due to circumstances and changes in the building process and the construction itself.

In terms of LCA process-based tools, there is a general lack of understanding. Every piece of software uses its own criteria and grades of importance to convert all the factors applying in the assessment [18]. Results are often expressed in uncommon reports or complicated graphs. Many of them don't have to take into account social and economic factors [19]. There are also green building rating tools, each of them with different criteria and weighting factors for same sustainability aspects, which makes almost impossible to compare evaluations of the same building with different tools [4].

This makes more difficult the relation between the stakeholders of the construction sector, from designer to final users. Even worse, they won't know what solution to adopt in order to achieve a level of sustainable performance during any stage of the building due to the different figures that the programs might show, depending on the subjective criteria used for the evaluations instead of the more scientific method for the Life Cycle of building processes. This poor integration of LCA models resulting in complicated outcomes makes project planning [20] and decision-making very difficult to balance at the correct building stage [21] since it's not adopted early enough and it becomes harder to be applied at later stages of the project process [20].
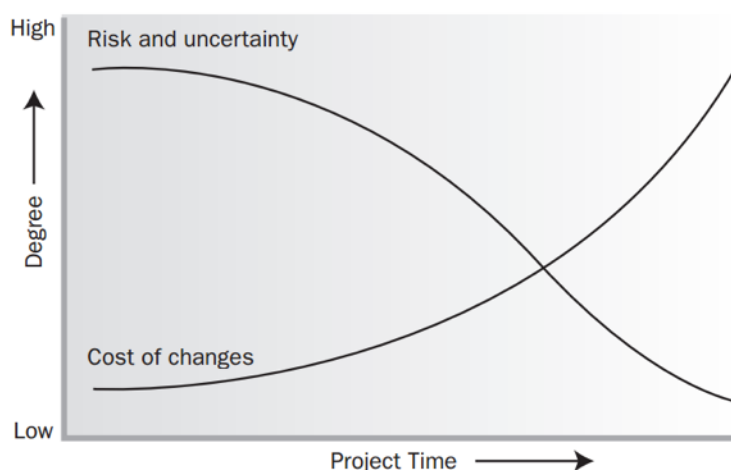
Figure 1.2: Level of influence and cost in building projects (PMBOK 5th edition)

Furthermore, it is very difficult to compare evaluations of the same building with different tools. Each environmental tool uses a specific impact method, very often even with different criteria [22], weighting and normalisation factors. In addition, there is a very low integration of social and economic factor what makes actual evaluations almost impossible to be easily indicated to the final user.

This project aims to investigate these challenges and develop a methodological solution by developing a simplified LCA optimization tool which could be utilised on new or existing domestic buildings at the earliest project level either for new or retrofit investments.

Ideally, all current LCA tools should share common criteria, with common units and common grade of importance when assessing the environmental performance of the built environment [23]. Due to the complex process of the building life cycle and all related industries, common factors are very difficult to achieve, so that a clear and simpler methodology would be very beneficial.

1.4. Thesis Objectives

The overall aim of this PhD is to contribute to decrease the environmental impacts due to current human activities within the domestic construction sector. This involves a wide range of actions between which quantifying the primary energy and equivalent CO_2 emissions from a building life cycle process are necessary to address.

The main research question addressed by this thesis is as follows:

- To what extent do the current Life Cycle Assessment tools, designed to evaluate buildings, cover the real needs to achieve the mandatory embodied and operational decarbonisation and optimization objectives?

When addressing this question, the following specific objectives were design:

I.   Bridge the existing low correlation between environmental assessment tools and reality.

II. Study and approach the whole building process and stages, from a holistic point of view, considering environmental impacts.

III. Review the existing literature regarding LCA methods and tools.

IV. Generate an updatable and easy to read environmental database of construction materials, expressing impacts by unit of area, included in the most common building typologies within the UK.

V.   Establish a calculation tool for environmental impact due to construction material's transportation, using different ways of transport.

VI. Establish a transparent methodology for LCA calculation method for new and existing domestic buildings, able to be applied at early design stage and retrofit investments.

VII. Incorporate a user-friendly and decision-making tool with calculation software to address the LCA of buildings including the optimization calculation currently necessary.

VIII. Set future possible routes for LCA tool development and certification process.

The aim of this thesis is to meet these objectives, and doing so, address the research question stated before.

These objectives also indicate the research methodology adopted, involving and extensive literature review and exploration of the topic.

Each of them is addressed by their own specific method, involving quantitative and qualitative analysis and they will be presented in more detail on the following chapters.

Simulation and case studies results arising from this thesis are deeply analysed on the corresponding chapter, followed by some conclusions and discussions of the main topic.

1.5. Limitations

It is very important to acknowledge the limitations of the project's goal and scope outline before. Particularly, having considered the wide range and amount of data and stages involved within this research, coming from very specific and individual material related data towards global and complex processes.

It should be noted that whilst subjects such as the environmental impacts, due to that multidisciplinary source of data involved, could be narrowed to a very high level of detail regarding lots of aspects and indicators. However, this thesis does not seek such a enormous level of detail which would fall outside the scope of this research as described above.

Studying the entire domestic project process involves all stages of the building from design, manufacturing, construction, operation and end of life. When involving such as wide range of materials and processes the complexity of data managed is also huge. Hence, a compromise between the levels of detail from the very specific terms until the most global issues needs to be accomplished.

This research uses information from literature and expert consultation from real world examples, when possible, in order to achieve the accuracy and that level of detail described above. However, some instances have been filled with a series of assumptions, mainly for time-related characteristics within the LCA stages, that are to happen in the future. These assumptions have been stated and justified as they arise every chapter of this document.

1.6. Thesis Summary

This research has been the effort and work of several years, some of them quite hard due to limitation from the international COVID-19 situation. The first two years were funded after scholarship applications were tried resulting in a granted co-funded full scholarship between the University of Strathclyde and BRE Trust.

This thesis starts by studying the "state of the art" in the construction sector, specifically the domestic one. Along that chapter, I was also enlarging my knowledge about the social housing and housing stock within the UK. Detail information is developed more specifically in Chapters 2 and 3 of this thesis.

A very detailed knowledge regarding the LCA within the built environment, its legal framework is indicated on chapter 3 followed by a deep analysis of the tools used for its calculation, having into account the clear evolvement that this subject has suffered within the last decades and will continue to achieve in the close future. Chapter 4 provides more detail of this study and highlight the key issues and gaps on research for LCA tools.

Chapter 5 presents the methodology and main actions of this thesis, after having identified the gaps in research and opportunities of the field involved. Here it is presented a meaningful contribution to knowledge, the development of a simplified LCA methodology and user-friendly tool. The development of a calculation tool was started with Microsoft Excel software.

Many difficulties were fronted since then and collaboration with BRE experts in the field was crucial and very welcomed. Although having started with M. Excel, the calculation matrix needed was too complex, and lot of data had to be involved. Hence, spread sheet was not enough if the outcome wanted was a simplified methodology with a user-friendly tool and yet considering a big and updatable scope and boundaries. Matlab was the software used for this task giving the capability to involve much bigger datasets and calculation processes in a more refined look and optimised experience by both developer and future potential user.

Three case studies were performed and variations within them, giving as a result a total of eight simulations. New and existing buildings have been studied. The retrofit option study were conducted with the collaboration of BRE, easing the access to its Innovation Park facilities. I also had the opportunity to perform a case study having access to CCG building sites referring to timber kits and CLT construction methods

as part of a research group involving Glasgow and Napier Universities and CSIC. Numerical results from those studies and models are then presented in Chapter 6.

Having established a base for LCA validated calculation, Chapter 7 includes the sensitivity analysis of that validation accomplished, as well as a deeper comparison between results obtained from case studies and key factors to have into account for sustainable growth and possible extensive research work. This chapter also adresses the potential impact of this research with a detailed view of the results obtained from the presented LCA tool.

Chapter 8 includes conclusions and discussions arising from this thesis, as well as the potential future work that might continue in order to further develop this research.

As a result of all this effort, some achievements have been accomplished. The most important has been the followed by a much deeper knowledge of the field: Life Cycle Assessment and sustainability on the built environment.

Initially some conferences and congresses publications were made and also work-related opportunities were obtained. I had the pleasure of assisting on some BRE work at their Scottish office, and meeting some of the best experts of this field. Currently, I work as "Sustainability manager" at Mace Management Group on the Life Cycle Assessment and Circular Economy area where I can apply and deeper develop this knowledge and experience.

1.6.1.   Outcomes arising from this research

The following poster presentations were attended:

Table 1.1: Posters produced during this research

Date & Location	Title & Occasion
2015-12th May Glasgow-UK	C.Campos and F.Bradley. "LCA methods for domestic buildings". *All Energy Conference*

As part of the research project, the following outcome has been produced:

Table 1.2: Presentations produced during this research

Date & Location	Title & Occasion
2015 2nd December Edinburgh-UK	C.Campos. "LCA methods for domestic buildings" *SEDA Show&Tell*
2016 November Birmingham-UK	"New simplified LCA methodology for new and existing buildings" *BRE Trust Conference*
2016-21st-22nd June Madrid-Spain	C.Campos, D.Kelly and J.Grant. "Red de Parques de Innovación BRE – Informando al futuro de nuestra construcción" *III Nearly Zero Energy Building International Congress*
2017-6th-7th April Guimaraes-Portugal	C.Campos. "Simplified Matlab Tool for Life Cycle Assessment for domestic buildings". *International Conference SYMCOMP17*
2018 19th March Glasgow-UK	C.Campos. "LCA methods for domestic buildings" *Low Energy conference*
2022 Seville-Spain	Publication paper submission in collaboration with University of Seville – department of construction (still to be published)

2

CHAPTER 2: CONTEXT AND FRAMEWORK

2.1.   Climate change and Sustainable development

2.1.1.   Climate Change and Kyoto protocol

According to the "Met Office" climate change is a "large-scale, long-term shift in the planet's weather patterns or average temperatures" [24]. In regard to NASA description, it is referred as a "change in the usual weather found in a place" [reference NASA website].

Although the vast majority of the effort is being focused on GHG emissions and energy demand reduction, climate change is already affecting all countries and regions in its daily basis in different ways.

It is affecting arising the average temperature in almost all regions in the world, producing the so-called global worming effect. It is discovered that temperature of the planet surface has risen by almost one Celsius degree from 1901 to 2012 which compared with Earth's climate change patterns is very high [24].

This climate change is affecting not only in higher temperature in recent years but also in the raise of annual rainfall water [25].As demonstrated in various countries, last winter 2015-2016 extreme big flooding lead to immediate climate risks.

The Kyoto Protocol [1] is an international treaty, which extends the 1992 United Nations Framework Convention on Climate Change (UNFCCC) that commits State Parties to reduce greenhouse gases emissions, based on the premise that (a) global warming exists and (b) man-made CO_2 emissions have caused it.

The main goal of the Kyoto Protocol is to control emissions of the main anthropogenic (i.e., human-emitted) greenhouse gases (GHGs) in ways that reflect underlying national differences in GHG emissions, wealth, and capacity to make the reductions. This protocol set up certain targets for CO_2 reductions and uses a base year, which is comprised of 1990 for carbon dioxide (CO_2), methane and nitrous oxide and 1995 for fluorinated compounds (F-Gasses) such hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride, for measuring those targets which are country-specific.

When the Kyoto Protocol took place in 1997 the society got concern about how important the greenhouse gasses for the environment are, especially the CO_2 as the main gas of the global warming issue.

Each of the six gasses included in the Kyoto Protocol are weighted by its Global Warming Potential (GWP), so that total greenhouse gas emissions can be reported on a consistent

basis. This thesis follows the characterisation factors given by the IPCC Assessment Report 5 [26]. In order to do that the following basic definitions need to be addressed for non-flourinated gases:

- *GWP=Global Warming Potential as its warming influence relative to that of carbon dioxide in a period of time that could be 20, 100 or 500years. It usually 100 year reference is given.*
- *GWP index of 1 Kg of CO_2 = 1 → 1 $KgCO_2$ x 1(GWP index) = 1 $KgCO_2eq$*
- *GWP index of Methane (CH_4) = 28→ 1 $KgCH_4$ x 28 = 28 $KgCO_2e$*
- *GWP index of Nitrous. oxide (N_2O) = 265→ 1 KgN_2O x 265 = 265 $KgCO_2e$*

2.1.2.   Sustainability

The sustainable development is being defined by the Brundtland Commission [27] as "human's ability to make development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

The UN 2005 World Summit [28] refers to sustainable development to "the interdependent and mutually reinforcing pillars: economic, environmental and social".

Trying to predict the future seems to be a very difficult task. It seems to be a more accurate prediction, having into account the actual technology and industry practice, what it's understood as a non-sustainable behaviour, which could lead to severe problems in the future. Those problems could be recoverable and predictable or not and there is an actual problem which is the climate change. If this is predictable why is there this problem? Probably it's because the current model used is not accurate enough and has not the potential to cover what a sustainable development should involve.

Table 2.1: Prediction and recoverability from future problems

	Predictable	Unpredictable
Recoverable	TV phase out	Small Earthquarke
Unrecoverable	Species extinction	Massive Earthquarke

2.1.3.   Sustainability within the construction sector

Many authors argue that the interactions between our built and natural environment are complex and have a great impact on the planet [29]. These impacts are very complex to quantify and value even using current methods. The whole construction sector and its associated industry are trying to minimise those impact figures, since all stakeholders are currently tending to improve their net emissions including all processes involved within their services [30] accordingly [31]. Part of this improvement can be seen in the increasing awareness of the circular economy and the effort toward the reduction of both the construction emission and waste [32].

Today's concerns about environmental sustainability involve the maintenance of current levels of natural resources and even to enhance them while improving the quality and performance of the consumer technology. This will be directly related to an improvement of the current living standard to which we are accustomed.

The economical sustainability, within the modern market model, tries to achieve those good quality products at a lower rate, taking into account the circular economy factors of the products. Therefore, considering the current industry technology [33].

Social sustainability is probably the most important feature within the social development of the human being. Which define the concern about increasing life quality and reducing human disturbance within the built environment.

These three main topics are probably the most challenging task, which falls directly on architects and developer shoulders, on which the responsibility of producing a quality construction sector is based on.

This brings us to the following question:

-    How is sustainability measured when developing a building?

A large part of the building sector is concerned about the global warming and climate change issues [34]. Social and economic factors are starting to have a relative greater importance within the circular economies although they are not included in the scope of this research. Using renovated and more transparent energy models and life cycle assessment methods could lead us to a more sustainable and lower impact construction practices.

In order to measure how that sustainability is achieved, a number of parameters are used. A finished building is obtained with after a wide range of human and economic

resources are spent. It also involves, usually, a large time scaled planification. Within that building, not only natural resources, transformed on construction materials, are used but also different processes are accomplished in which human resources and products are aligned.

Those products are manufactured using natural material resources obtained from the environment, then transported and processed to become construction products ready to be used within the building. In all those tasks, carbon emissions are released into the atmosphere and energy, produced by any source, is consumed in order to get all those processes done.

Once we get those construction materials, they need to be brought on-site, where more processes and energy is spent to get the building finished and ready to bu operated or used by the final users.

These final users also need to spend energy in order to keep those buildings within the comfort zone and with quality standards that make those spaces liveable for the main use they were design for. Furthermore, when the building gets old and makes it almost impossible to continue living in it with minimum conditions of quality and comfort it must be demolished, thus producing a large amount of waste whose end is usually a landfill in a high percentage of cases.

Hence a building life cycle has been described, and embodied and operational energy an carbon have been addresses during the material and processes involved.

The correct use of these measurable parameters with the most suitable assessment tool would help better to achieve the environmental targets set up by all governments and countries involved in the mentioned Kyoto protocol.

These parameters and the building life cycle stages and the repercussion of each of them are widely explain on next chapter.

2.2.   The construction sector impact

The construction sector is currently responsible for a high percentage of the environmental impacts produced by the developed countries. In the European Union, it is responsible for roughly 40% of the overall environmental burden [35]. With respect to homes in the UK, when you include their construction impact and energy consumption during occupation, they are responsible for the consumption of 40% of primary energy in the country [36]. This sector therefore currently has become a major target area for improvement and is generally addressed by most environmental policies [37]. With regards to the domestic sector in Europe, it consumes 20% of total energy and generates more than a quarter of CO_2 emissions; the housing sector is therefore a critical area of research in order to try to minimize these figures [38].

The energy used in constructing, occupying and operating buildings represents approximately 50% of greenhouse gas emissions in the UK following the UK environment agency report of 2007.

There is a clear interaction between design, energy utilization and CO_2 emissions during all stages in a building's life that clearly affects to the economic factor of a project considering the life span of a building and its users. For example, if less is invested in the construction phase (e.g. specification of poor insulation), the investment needed for heating and maintenance will increase.

As mentioned before, the wide use of the term "sustainability" is still difficult to addressed completely by one component if talking about construction. It is probably possible to narrow it breaking up all parameters involved, and then adding them up again, in order to go from the global picture to the specific, and then back to the global to be analysed after a detailed studied has been perform.

2.2.1.   Embodied vs. Operational Impact

When addressing the environmental impact of a building, terms like embodied and operational, both referred to energy consumption and carbon emissions, come to action. Following the definition of *embodied*, this term is defined as "an expression of or give a tangible or visible form to (an idea, quality, or feeling)".

The operational term refers to every process involved during the using life span of the building needed to keep it under correct use and user-comfort level.

This means that when talking about embodied energy it involves all the energy that is used to produce a material or product including manufacture and transport and final processing, once the product is no longer valid for its primary intended use.

On the other hand, embodied carbon refers all carbon equivalent emissions released into the atmosphere when conducting all those processes for which the energy is consumed to get all those building product, including transportation on-site construction and the end-of-life of product process. However, operational impact refers to energy consumption and carbon emissions released during while the final user operates the building within correct and normal comfort level of use. This is, impact that air conditioning, cooking, watching TV…etc produce to the environment.

Embodied versus operational concepts could be summarised as follows:

- The embodied impact of a building refers to the environmental burden that using the construction materials, to build it, do produce or will produce. They could be summarised as the 20% of the total impacts of building [39, 40] for a 60year life span of a common building.
- The operational impact refers to environmental damage produce from the normal use of the building by the final user. This impact could account for almost the 80% of the total impacts over a 60 year period [39, 41].

In order to be able to measure all these impacts, general life cycle assessment would need to be addressed having into considerations that operational impact measurement is an on-going task during the use period of the building. Hence, assumptions with clear scenarios should be created in case of anticipating those impacts and measuring them prior the final user operate in the building. Although many European countries have developed an energy certification process for residential and non-residential buildings, the variables considered may differ between software and countries. Energy models become necessary within the correct environmental impact strategy used with real weighting factors applied [42]. Hence, the use of accurate and complete Life Cycle Assessment becomes essential.

2.2.2. Toward net zero carbon buildings

Once we have measurements of the global impact that building would produce over a complete life cycle, we could allocate the exact amount to embodied and operational impacts to the different processes and products. Thus, start thinking and developing strategies and mitigation solutions applied to reduce, or eliminate completely, those impacts.

This research focuses on domestic buildings, for which net zero carbon strategies are commented. However, these measures could be similar than the ones applied for other building typologies.

First type of impact address by local governments and the industry sector is the operational one. This impact could be reduced with the following, but not only, measures:

- Improving the performance of current equipment used within a domestic building [43].
- Improving the design for domestic building to need less energy to achieve the comfort level desired for the user [44].

On the other hand, if we talk about improving the embodied impact of a building, we could talk about the following objectives, between others:

- Improving the manufacturing process when producing construction materials.
- Improving the building process to get a more efficient construction strategies.
- Increasing the reuse and the recycling rates followed by industry transformation.
- Improving transport efficiency, trying to get more 100% loaded transportation of materials and considering the transfer to hybrid or electric vehicles.

This could mean i.e. using more efficient boilers, attempt the transition from natural gas to electricity for kitchens, or change old central heating machines for new ones with lower energy consumption, thus, less impact to the environment too.

Although current industry has its own limitation in terms of efficiency of new technology production and better equipment , local governments are defining new strategies and building regulations to achieve the desired Net Zero Carbon buildings [45].

As it could be thought, zero carbon buildings would mean zero energy consumption and zero carbon equivalent emissions. This would mean the following:

- The building materials are obtained with 100% reused or recycled material with no-impact-processes involved, or processes in which only clean energy or electricity is used.
- While the final user operates them it consumes the energy that it produces itself (i.e. PV panels), and its capable to produce with 100% renewable resources which are considered to have zero carbon emissions.
- After the building is used and need to be deconstructed or demolished, all materials are diverted from landfilling sites. And then directed to new materials cycles for building or other sector use.

Despite the fact that currently industry and technologies are not prepared to achieve that level of incredible performance, we could try to get there, at least at the operational level. Although this target is obviously impossible to achieved, trends aim to get a net zero balance. Some impacts are impossible to eliminate, such as a proportion of manufactured products or operational consumption. However, maximum reductions could be attempted [46] *i.e. having a 100% clean electricity supply which is only produced from renewable resources. This would mean that electricity consumed within the building would have zero impacts to the environment.* It could also be desired to get *materials manufactured with 100% recycled product. Hence natural resources impact would be zero.* Still then, remaining impacts are not eliminated.

When impacts have been reduced to a minimum but real net zero balance is targeted, the remaining impacts could be accomplished outside the building with carbon credits or off-site compensation projects. i.*e.3. reforesting forests or improving animal bio habitat, hence, capturing CO_2 from natural trees or plants.*

2.2.3.   Waste Generated

Construction and demolition waste (C&DW) represents alone the 32% of the total UK waste [47]. It also represents a very important figure within the European union where is one of the most important streams generated accounting for the 25% to 30% of all waste generated with recycling potential [39]. It shows the clear impact that this waste generates to the atmosphere and the massive improvement potential that building's stakeholders could consider when reducing those embodied carbon and energy consumption figures allocated on only waste generated.

Having into account that almost the 50% of materials extracted from earth [48]are building related, and those buildings generate the major share of waste across the EU-28, it is assigned a huge challenge to narrow those figures for all stakeholders.

Only concrete itself, represent almost 75% of all material resources extracted for construction, having the steel and wood in buildings accounting for 21% and 37,2% respectively [48].

Current recovery rates from construction waste must improve in order to reduce carbon emissions associated to C&D waste and landfilling final disposal. This way, circular principles toward which the construction sector should trend would be more liable and embodied carbon figures reduced [33].

2.3.   The domestic sector

As it was stated in before, the domestic sector is responsible for the 29% of the overall energy consumption within the construction sector in the UK.

This thesis focuses on social housing sector often resulting with hard cost constrains and problematic families socially and economically.

2.3.1.   Social housing in Glasgow

The post-war housing shortage and processes of industrialization in the early nineteenth century in junction with a vast urban population growth led to an urgent need for more housing. Wealthy families moved to the suburbs and the constantly increasing working class population remained packed in the city centre with high densities rates [49]. In 1861, after a wave of immigration from Ireland, 62.5% of the Glasgow population lived at densities of more than 2 persons per room and in 1921 40% of the population still lived in this density [50].

As a result, in the mid nineteenth century a huge amount of people was contained in Central Glasgow and in the 1920s and 1930s the city had a very high level of slums. Indeed, by 1945 a third of Scotland's population was compressed at the City Centre of Glasgow [51] and the housing crisis in Glasgow was universally acknowledged.

Social housing in Glasgow as it is known nowadays has it base after the Second World War. The four main housing states in the Periphery of Glasgow have attracted international attention even if their publicity had been negative in almost cases. Anyway, social housing supply is been a long-term problem from two centuries ago in Glasgow due to the population growth suffered since then [52].

2.3.1.1.   Peripheral States

In 1951, Robert Bruce and the Glasgow Corporation recognised that the overspill population had to be transferred away from Glasgow to new towns and areas beyond it. And so, during the 1940s and 1950s four huge peripheral housing schemes were developed outside Glasgow. Pollock in the south-west before WWII and finishing in 1951, Drumchapel in the north-west which started in 1951, Castlemilk constructed in the south in 1954 and Easterhouse on the east in 1955 [53].

Figure 2.1: Glasgow`s four Peripheral States (CES Ltd, 1985)
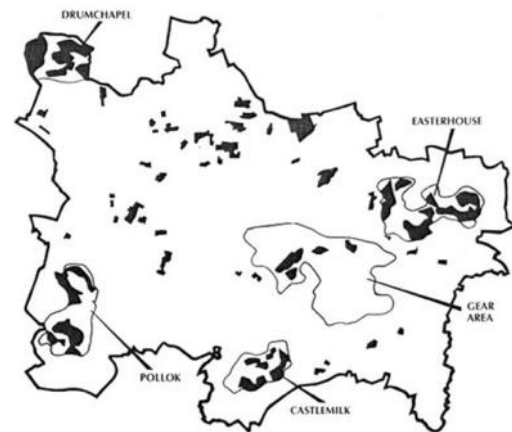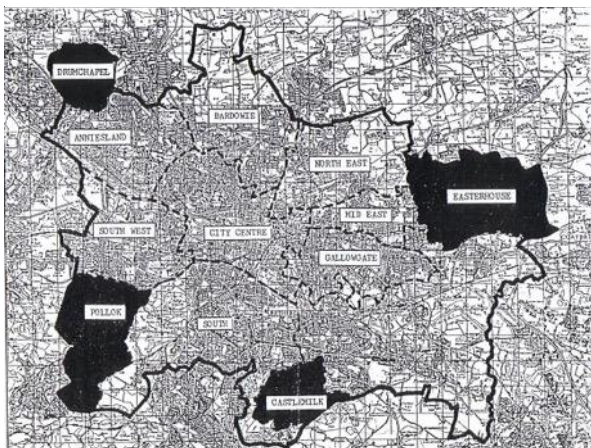
Figure 2.2: 20% Most Deprived Areas in Glasgow, 1981

While these four huge new estates were settled during the 1940s, the destruction caused by the war meant that by 1950 the housing problem in Glasgow reached epic proportions [52] and the number of people waiting to be reallocated made that the peripheral states had to be finished as quickly as possible. In fact, according to the industrialism dominant by then, all the new housing schemes were built in pre-cast concrete structure with almost no insulation at all resulting very poor comfort performance housing not asset at that moment.

It was originally envisaged that the advantages of living in the peripheral schemes would include the construction of new schools, shops and other social facilities. It was also hoped that with a labour pool, small business and industries would be able to generate new employment for a large number of the new residents.

However, the very good initial feeling became a disaster for the families that used to live together and now they were separated by miles of land. Also the new schemes changed the family's way of life completely, since the new accommodation until the

new luxury areas they had never experienced and even the new infrastructure, as they had to go to the city centre every day [52].

Families were no longer close to each other. Visiting a friend became a long and expensive trip. The quantity of shops and amenities that was expected never came true. In addition, the poor energy performance of the housing buildings (majority Orlit [54] and Airey [55] typologies) originating energy problem after 10 years and with the rising prices of the fuel due to the fuel crisis. The poor ventilation and heating systems caused condensation that unfortunately led to dampness affecting many properties.

The lack of facilities caused young people to turn to vandalism, a trend that continued for many years. Gang warfare was endemic and the estates created a bleak and cold environment for those living there. Basically, the council had moved a big social problem to the outskirts of city.

2.3.1.2. Housing Defect Acts

After the war house shortage and the boom of non-traditional methods of house construction due to its construction speed. These constructions were mainly developed by local and public authorities.

In the earlies 1980s the Building Research Establishment (BRE) revealed problems in those methods used due to rusted rods within the precast concrete elements. This is why the Government initiated a scheme of assistance for people who had purchased a defective house from a public authority. Despite of the overall precast concrete defect, they were widely poor insulated.

There were a lot of typologies such as "Orlit" or "Airey" and variations of housing buildings "designated defective". All those buildings had to be repaired and renovated in order to be habitable.

2.3.2.   Housing Stock Change

The building stock has changed in many ways over the last 50 years. Post-war houses were an unimproved brick terrace with coal fires and outdoor sanitation [56]. Some of them still exist today after a couple of waves of modernization like central gas or refurbishment.

There are a lot of possible combinations in how to manage all that building stock in terms of sustainable energy performance. It is known there are some environmental targets for reducing by 80 the CO_2 emissions by 2050. How will the old and new building stock perform in achieving those targets? Is LCA being taken into consideration in order to achieve targets? Are all the factors included in their LCA performance?

Those factors are not only the materials and energy used for construction and use stage. The life cycle performance of buildings has changed as well since the building stock in dependent on its role as a combined physical, social, economic and cultural asset [57].

The energy efficiency of homes has improved every decade going from an average SAP rating (Standard Assessment Procedure) for a UK home of 17.6 in 1970 to 56.7 in 2011 [34, 58]. The improvement in average SAP rating is due partly to the better efficiency of new homes (around 80), but mainly from the upgrade of existing stock. These figures involve social and private homes.
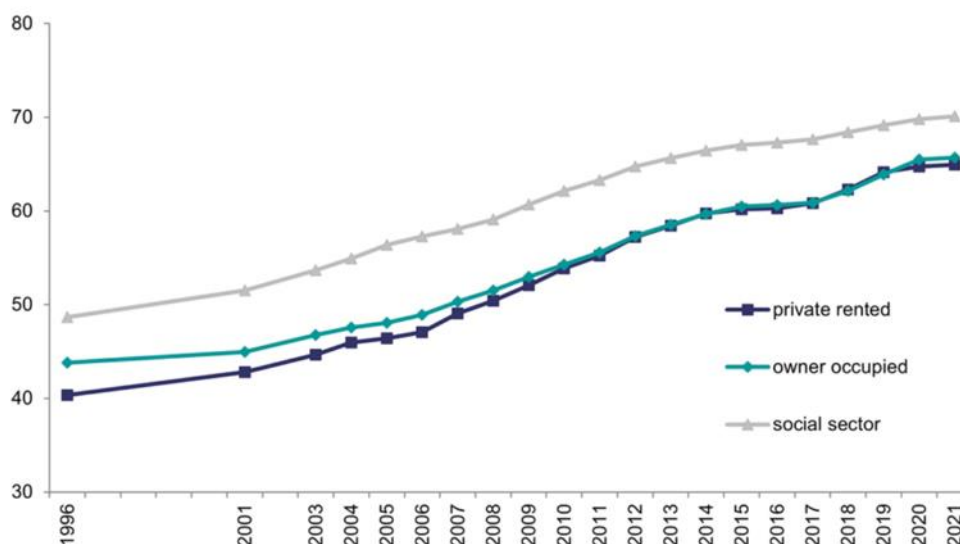
Figure 2.3: mean SAP rating, by tenure, UK Homes [59].

2.3.3. Refurbish against demolition

Although the renovation as possibly the best solution seems to be the right nowadays, the decision of the refurbishment or demolition and re-construction for social housing is a controversial topic discussed recently and still has not gotten a clear response on one of the two options [60].

That is the case exposed in a recent study called "Demolition or Refurbishment of social Housing? A Review of the evidence" [61]. That document states that refurbishment could lead to a lower cost rather than demolition and re-build and also better improvements on energetic and environmental issues. That study also talks about social factors such as the possible disruption (relocation and time), health improvement and better living standards are able to be gained with the refurbishment.

In addition, this question cannot be based only on energetic aspects, CO_2 emissions and economic cost. It also needs to involve social factors, renewal environmental results against re-build ones. It needs to assess the overall process in order to know which would be more beneficiary for the end user and the environment. This decision is also important for achieving the targets proposed by the UK in 2016 and imposed by the EU for 2020 and 2050 to reduce energy consumption and CO_2 emissions.

A case study has been carried out for a social house in Anderston, Scotland [62]. That study shows that the retrofit measures can achieve the same levels of energy efficiency and environmental performance as rebuild and if offers greater social and economic benefits. That study made by building computer simulations shows that by refurbishment is possible to achieve a 80% of reduction in carbon emissions and change the SAP rating from 11 to 75; the same as rebuild. It is also state that the LCA should get a further development by studying the strategy for low carbon homes and economic cost of refurbishment. Both things could be developed by new LCA methodology that this project aims to develop.

As previous case study reflect, the end of life of buildings has not been study deeply through the LCA of buildings [63]. That is the case of the social house study in Anderston [62] where the energy consumption and CO_2 emissions of the end-of-life weren't considered neither the construction process in the case of rebuild. In any case, that makes the case of refurbishment even more beneficial.

Another aspect not deeply studied on the literature available is the current ability of the industry to get the proposed targets for reducing the carbon emissions. Is the

industry ready to demolish and rebuild with new materials in a more efficiency way than refurbishment or major renovations? How to do that change?

To improve all these SAP figures not only is necessary to take care of the existing buildings but also of all other factors for new buildings like infrastructure, raw materials consumption, and circular flows during the whole life cycle, since urban areas are design to build (input) but not to be recycled (output). Therefore, information about size, kind and distribution of waste materials would be important in order plan sufficiently for treatments facilities and landfills, a clear estimation of this could make a contribution of design-efficient recycling models [58].

It is known that the refurbishment could be done using many different materials. So that, for social housing could be studied the best practice for the achievement of very good SAP ratings and low environmental impact through different options using LCA base processed approach.

The development of the strategy to follow for the end-of-life of buildings and construction process could be include into LCA approaches when assessing existing and new housing. If it is not included clearly and simple it could be due to the complexity of the process to assess those factors.

3

CHAPTER 3: LIFE CYCLE ASSESSMENT

3.1.   Life Cycle Assessment (LCA)

The Life Cycle Assessment, or LCA, was invented around 1970 at the Midwest Research Institute in the USA [64]. Its primary purpose was to compare packaging analysis under environmental impacts, especially waste produced [65].

LCA started to be used in Europe soon afterwards in Frankfurt, England, Sweden and Switzerland as a comparative analysis of packaging under environmental aspects with special attention to resource conservation and energy saving [65].

It was the time of the famous "Club of Rome" Report [66] and the first oil crisis in 1973 when it became obvious that our resources will not last forever and the economic growth might result in an environmental disaster. After the second oil crisis in 1979 LCA activities continued by a few specialists but at a more moderate level.

In the late 80s LCA had a sudden revival and many products were analysed "From Cradle to Gate" with the basic idea of all environmental burdens connected with a product or service had to be assessed, from the raw materials to the waste removal [65]. The basic idea is undoubtedly true and consists in the shifting of burdens.

In the years from 1990 to 1993, SETAC (Society of Environmental Toxicology and Chemistry) and SETAC-Europe shaped the development of LCA in a series of important workshops culminating in the "Code of Practice" of 1993[67]. The results of these workshops could be illustrated by the SETAC Triangle, which is now underlying the activities of ISO 14000 standards. These current ISO standards vary from the SETAC framework in the last phase "improved assessment" which is changed for Interpretation. Legal framework will be detailed in SECTION 3.2 within this chapter.
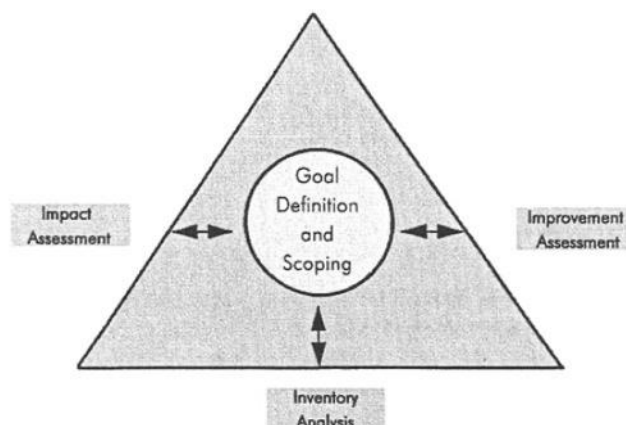
Figure 3.1: Phases of LCA Method according to SETAC (1993)

3.1.1. Life Cycle Assessment phases

According to this first life cycle framework, the following assessment phases were defined:

a) Goal definition and scoping.

This first component is the central part of each LCA. It defines the reason for performing the assessment, the boundaries, depth, systems analysed and the functional unit which will be evaluated.

This stage involves information such as geographical situation, technical and time, data collection, impact allocation and indicators that will be taken into account.

b) Inventory Analysis

This stage is the most scientific component of the assessment. It is probably widely known and understood part since it becomes easier to get quantities and flows of materials considered within the LCA process defined in the previous stage.

The key part of this phase is to produce a list with all inputs and outputs for all processes related to the functional unit described in the goal and scope from raw material extraction, through manufacturing to final removal. Transport and auxiliary products are often included. These processes are usually converted to primary energy figures or "Cumulative Energy Demand" [68].

c) Impact Assessment

Only with the LCI in terms of functional units listed is not enough for a comprehensive analysis of the product evaluated in terms of impact to the environment.

This phase is applied for a deeper understanding of the LCA process and systems with an impact method. This method is able to establish categories in which environmental impact will be detailed. The resulting categories could also be classified as input or output related. Then the quantitative data collected in the previous steps need to be transformed into actual impacts within the categories selected.

The method could be based on a midpoint or endpoint evaluation. In this thesis only midpoint impacts assessments is considered.

To get a complete LCA analysis, the following steps are needed [18]:

Classification

In this first step LCI data are assigned to the considered impact categories. The selection of these impact categories is based on the expected types of impacts.

Characterization

In this step the data classified previously is transformed according to a number which indicates the contribution of the product system per functional unit to the category considered. i.e. for Global Warming Potential, all impacts classified within that category are converted to CO_2 equivalents. So the unit for all inputs and outputs will have the same unit which for each category even if the impact comes from different GHG than CO_2 emissions [26]. These characterization factors were explained on section *"2.1.1 Climate Change and Sustainable development"*.

Normalization

This step involves the use of ratio of indictor per functional unit for every category to stablish a common reference and enabling comparison of different impacts. To achieve this aim, a reference quantity is used to make the data 'dimensionless'. In this work, normalization is not needed since a midpoint evaluation is performed.

Valuation or "Weighting" (interpretation for current ISO 1400 Family)

This is the subjective part of the assessment in which impact categories are valued in regard of the resources and quality. Products with different values on the impact categories are not comparable directly. Some products may be better for category A, some other for category B, so it is very hard to declare which one is the best globally. Including these subjective factors every category would be given a proportion of importance and hence, a complete score is given.

This is the step in which the findings for the LCI and the LCIA are considered together. This phase should deliver results that are consistent with the goal and scope defined at the beginning of the assessment and reflect the approach in which they are based. This could be an iterative process of reviewing and revising the scope of the LCA project.

3.1.2. Environmental Impact Indicator

According to ISO environmental management standards [69], the definition of environmental impact is "any change to the environment, whether adverse or beneficial, wholly or partially resulting from an element of an organization's activity, product or service that interacts with the environment".

According to the same standard, environment is the "surroundings in which an organization operates, including air, water, land, natural resources, flora, fauna, humans and their interrelationships".

Indicators are measures (quantitative, qualitative or descriptive) which when periodically evaluated and monitored, show the direction of change [70]. Indicators are measures corresponding to the criteria. Criteria are characteristics that are considered important and by which success or failure is judged.

Therefore, indicators are the values in which the environmental impacts categories are measured. For current sustainability standards [2, 71] impact categories are many and difficult to understand [72] for non-experts. It becomes very complex to see how the total figure, given by the weighted indicator, actually affects to the environment. For this reason, simple and straight forward global indicators are needed.

After convenient indicators are achieved, they are added by element and LCA stage, following the environmental impact calculation matrix given by current Standard of Sustainable of construction Works (EN 15978-figure 9) [3]. These current standards are explained after in this chapter.

A criterion may consist of more than one indicator. Qualitative criteria and indicators are open to interpretation by assessors and therefore less certain and they can also use quantitative indicators in the evaluation. Using qualitative and quantitative indicators forces to weight the indicators in order to use a rating system [73]. Otherwise using indicators with different units would be impossible. The nature of the unit may differ [74] and results might be different depending on those units used.

3.1.3. Impact category

The assessment of the impact of a specific product may involve different process and flows and formats. This is where the impact category become important since it will unify all flows through the impact indicators selected and will result on a measurable and comparable unit that will be called "equivalent".

For example, the impact category 'climate change' is expressed in kg CO_2 equivalents (kg CO_2-eq). However, other greenhouse gas emissions than carbon emissions (CO_2) cause climate change as well. Such as methane (CH_4). By expressing these other GHG emissions with different measuring units in kg CO_2 equivalents, this impact category makes it possible to come to a single metric for climate change.

3.1.4. Midpoint vs endpoint method

The impact of any product is measurable throughout its life cycle. In order to quantify that impact, there are different impact methods to consider. Methods could difer between each other on many aspects, one main distinction is midpoint or endpoint methos. Each of which will give a different level of detail within the results.

Endpoint methods are based on a global scored for each of the impact categories considered. It looks at the environmental impact at the end of the cause-effect chain. They are typically expressed as an impact on human health, ecosystem quality or resource depletion with a higher level of uncertainty, since wigthing factor had been applied. These three endpoints capture the effect of many other endpoints involved within them such as "Climate Change".

A midpoint method gives as results the impact at an earlier stage along the cause-effect chain. This is before the endpoint would be reached and it offers a lower level of uncertainty since it does not have normalisation step involved. This could be "Global Worming Potential".

In this thesis, the following impact category and indicators are considered:

Impact Category:

-   "Climate Change"

Category indicators:

-   "Global Worming Potential" (GWP), measured in $KgCO_2$ equivalents.
-   "Non-renewable Energy Use" (NREU), measured in MJ.

3.2.   LCA in the Built Environment

Due to the high environmental impact of the building sector in terms of energy consumption and GHG as has been explained in section 2, it represents a major target for improvement generally addressed by the local authorities with urgent need of actions.

LCA should be part of the design process as a decision making support tool, to be used by the designers of the building in parallel with other aspects such as circularity and functional requirements [75]. There is no doubt that LCA methods contribute significantly when pretending the goal of sustainable development within construction. It provides a methodological framework to measure and monitor environmental performance of buildings [76].

The "Goal and Scope" phase in the LCA of buildings depends on the stage(s) studied or the boundaries that will be taken under consideration depending on how detailed the assessment will be.

Nevertheless the "Life cycle inventory" (LCI) in buildings is a very difficult task [77] due to the high rate of different materials and processes involved. Off-site manufacturing for building products is rising but at the moment every building is not that much standardized like most manufacture goods because of the unique character of works. Therefore the "Impact Analysis" is often an arduous task carried out with the help of complex computer software tools given the large amount of data to analyse and evaluate. Even so this task can last days or weeks.

For this reason, current standards and procedures [2] tend to organize how the building could be studied in terms of environmental impacts including all kind of processes involved within the complexity of one building construction. It is known that this task itself could last for years since the first project plans until the final product, ready to be used by consumers.

Regarding this reason, despite the four stages for the general LCA process, the impact assessment of buildings has also been divided on different stages in which could be allocated all GHG emissions and energy impacts coming from that really hard task of building.

3.2.1. LCA Stages

This section explains the environmental stages that are involved when performing LCA of buildings, which is the core of this PhD. However, it also gives some assumptions and explanations that have been taken into consideration within the simplified methodology proposed for new and existing domestic buildings.

Despite of the phases addressed by the ISO standards in a Life Cycle Assessment for any process there are specific LCA stages when the item or unit assessed is a building [29] and they are described on EN 15978 [3] .

As stated on the following table, stages go from A to D with some sub-stages each one. Impacts are usually divided into embodied and operational:

- Embodied impacts include sub-stages A1-A5 + B1-B5 + C1-C4. They are impacts that come from the materials used in construction, the manufacturing and installation processes from the proper need when constructing a building.
- Operational impacts include sub-stages B6 and B7. They come from the normal use of the building itself when users operate them.

When assessing a building regarding its environmental impacts, assumptions need to be made to predict some sub-stages for which information or patterns of use are not always as clear as desired. These are the previously indicated sections as "scenarios".

This means that when performing LCA of buildings, those scenarios should be clearly stated in order to demonstrate which of the possible selections and assumptions are taken into consideration for that particular environmental analysis.

Main stages could be summarised as follows:

Table 3.1: LCA Stages in the building process

Stage	Process		LCA stages related				
A Manufacturing	Product	A1	Raw materials		CRADLE TO GATE	CRADLE TO FINAL COMPLETION	CRADLE TO GRAVE
		A2	Transport to factory site				
		A3	Manufacturing process				
	Construction	A4	Transport to building	SCENARIOS			
		A5	On-site construction				
B Use Stage	Use of the building	B1	Use				
		B2	Maintenance				
		B3	Repair				
		B4	Replacements				
		B5	Refurbishment				
	Operational use	B6	Energy consumption				
		B7	Water consumption				
C End-of-Life (EoL) Stage	End-of-use	C1	Deconstruction /				
		C2	Transport of waste				
		C3	Waste processing				
		C4	Final disposal				
D Benefits Beyond the EoL	Benefits for environment	D1	Reuse				
		D2	Recovery				
		D3	Recycling				

All these stages are also considered at different levels of assessment i.e. LCA of products [78]. Environmental impacts of products themselves are regulated with ISO and European standards and expressed with reports called "Environmental Product Declaration (EPD) [78]. Although all stages could be considered for either EPDs and LCA of buildings, not all of them are mandatory when performing those product's environmental evaluations. Only those stages marked on the previous table are mandatory when reporting any EPD of a specific product or family of products [23].

3.2.2.   LCA Stage A – Manufacturing process

Manufacturing stage involves all processes from extracting raw materials until the final complexion of the building itself. It is, therefore, one of the main sub-stage for embodied environmental impacts when performing the whole LCA of a building.

All this procedure has 5 substages that are named from A1 to A5. The first three are usually aggregated and given all together into a joined substage called "Manufacturing A1-A3" Last two stages are under the so called joined substage "Construction process A4-A5".

3.2.2.1.   A1-A3 - Material manufacturing

- A1: Extracting materials

This process involves the extraction of the raw materials that will be used to produce the construction material used on-site later.

- A2: Transport to manufacturing factory

This section involves the transportation of those raw material to the factory itself. According to current standards, materials usually travel more than once before arriving to the final consumer and then going to site. From the factory, in which they are manufactured, they go first to a trade (or sale) point. Sometimes even they go to more than one sale points. All those transports are included within this substage.

- A3: Manufacturing process

This stage involves all processes included on the manufacturing process which obtain a final construction product from the raw materials extracted to manufacture it.

These three stages are usually given together as a unique stage. Environmental data referring to manufacturing process include i.e. the embodied energy and carbon data which come from the addition of the A1-A3 data from all materials involved. Although packaging process and materials could be also included in this section, these are not part of the scope of this research and hence they are not considered for the proposed assessment tool, nor for waste amounts coming from them. These are also the only mandatory stages within the product level EPD [78].

3.2.2.2.   A4-A5 - Construction process

- A4: Transport to site

Impact referring to this stage are only those from the final trading point to the building site. This means since the final consumer gets them until they are used within the building.

The transport loads that the proposed simplified methodology considers involve only transportation of materials from the "trade point" to the building site. This means that the factory gate could not be the trade point from which the transport is accounted. This occurs because is very difficult to establish a distance from factory gate of all materials involved within the building sector and by default that transport is voided, if that is the case.

- A5: construction process (on-site)

This stage involves the complex process of the construction of the building, using all materials and processes happening on-site until the final complexion of the building itself.

Some of the processes are the Installation of all materials, energy and water consumed onsite, ancillary materials and the disposal of any amount of waste produced from those tasks.

This means that i.e. for 1m2 of brick's wall is actually needed more than 1m2 due to breakages and errors or damaged items. This extra quantity of material needed also need to arrive to the building site even if they won't be used for the actual building itself and will be considered waste and directed to final disposal. The impact due to "gate to site" and "site to landfilling" transport of this extra amount of material needs to be allocated within this construction section, LCA Stage A5, and not within the Transport A4 sub stage nor the End-of-life C1-C4 stages.

3.2.3. LCA Stage B – Use

This stage involves all process that occur during the life span of the building, also known as "Reference Study Period". It is usually measured for 60 years. However, there are some building typologies that may be analysed for a different span.

During the life span of the building, transport of products from "gate to site" and from "site to landfilling/treatment plant", and construction process that may occur for this stage should be allocated within the corresponding sub-stages.

3.2.3.1.   B1 – Use phase of the building

This stage involves all impacts during the normal use and life span of the building. Such emissions could be any release of substances from the coated surfaces, or refrigerant fluids from air treatment machines.

3.2.3.2.   B2 – Maintenance

This stage considers all activities carried out for the correct maintenance of the building itself. These activities could include both preventing and regular maintenance such as cleaning of floor or replacement of rubbering seals of a window.

3.2.3.3.   B3 – Repair

This stage involves all works carried out in order to fix a component of the building in order to return it to the required technical performance. Such as replacing. Broken glass of a window.

3.2.3.4.   B4 – Replacements

This stage involves all impacts regarding the process of replacing all damaged components of a building that cannot be repaired instead or that have come to the manufacturer end of life before the building study period.

3.2.3.5.   B5 – Refurbishment

This stage involves any major work carried out to renovate or change the visual aspect of the building. Such as changing the façade finish or placing a new partition wall in order to get an extra room.

3.2.3.6.   B6 – Operational energy use

This section considers all energy consumption used during the life span of the building from building integrated technical equipment [79] .The energy could be either regulated or non-regulated depending if it comes from a fixed equipment such as HVAC, lighting or hot water treatment, or from non-building related appliances such as mobile phone charge. If this is the case, they would need to be reported separately.

Within the UK, this energy consumption could be modelled or obtained from the Standard Assessment Procedure (SAP) used for the energy rating of the buildings.

Within Spain, this energy consumption could come from the Energy Certificate of the building, which also includes any energy generation for own use.

For both countries there are some benchmarks that could also be used for LCA of buildings, which is the case of the proposed simplified methodology. This is because energy modelling could be a major task itself and it's not the aim of this PhD to accurate present energy demands of buildings.

3.2.3.7. *B7 – Operational water consumption*

This section takes into account all the volume water consumed for the normal operation of the building during the reference study period. This module excludes water used for maintenance, repair or any work that should be allocated within the previous sections.

3.2.4. LCA Stage C - End-of-Use

As it was stated before on the summary, this phase involves four different stages: demolition, transport "site to landfilling", waste processing and final disposal. When evaluating this section and its sub-stages, assumptions should be made since the tasks involved are due to happen in 60 years time.

3.2.4.1. *C1 - Demolition or deconstruction*

The demolition process involves the deconstruction and disassembly works of the building. Heavy machinery or cranes are usually used for this task so environmental impact comes from the fuel and energy usage. It is usual to have these impact in terms of indicator by m2 or by m3 since it is very difficult to get accurate environmental data from building sites.

3.2.4.2. *C2 - Transport of waste*

This section includes impacts from the transportation of waste produced fom the building demolition to landfilling sites or any treatment factory in which waste would get the end-of-waste line.

3.2.4.3. *C3 - Waste processing*

This sub-stage includes all impacts from any process helping the waste to get that end-of-waste line. Hence, any process that would transform that waste into a new product ready to be used again.

3.2.4.4. *C4 - Final disposal*

Final disposal environmental impact comes from landfilling sites processes. They usually come from the fuel machinery used for the movement of all materials from construction sites within the landfilling site area. These impacts are usually given in indicator by m3 of material landfilled or treated.

3.2.5. LCA Stage D - Benefits beyond the end-of-life

This module represents the possible benefits that possible circularity of the supply chain could have diverted the construction waste from landfilling or its usual end of life state. It could be considered as the potential environmental benefits of the building or products.

Hence, the benefits could occur when the environmental impact resulting from using treated materials (after EoL) is less than the impacts from using new raw materials, for A1-A3 module or "business-as usual" scenario. This section is not mandatory and usually it's avoided when analysing the LCA of a building, having into account that it's very unlikely to know how the industry or technology could treat materials in a sustainable manner in 60 years time.

This section could also be divided into three main processes:

- Reusing: this would be the first attempt of possible environmental avoidance. This include other tasks or possible uses that the same material could have after the building has been demolished.
- Recovery: it involves any process from which energy or heat could be recovery from the material's transformation. i.e. incineration of timber products.
- Recycling: if material cannot be reused but circularity has a clear environmental potential, it could be treated

As it was said before, this LCA stage is not part of the scope of this simplified methodology. However, it could be use just as reference. This stage could be extended after the PhD project as part of the future development works.

3.2.6. Social and economic factors

Although social and economic factors have been analysed, this thesis does not consider them within the scope of its objectives, when incorporating them into the proposed calculation tool. However, some concepts that could be the subject of future studies are detailed below. Both, social and economic factors are regulated by BS EN 15643:2021 [80].

According with that standard, social factors that might be included within the LCA of the buildings are the following:

- Accessibility.
- Adaptability
- Health and Comfort.
- Impacts on Neighbourhood
- Maintenance.
- Safety and Security.
- Sourcing of materials and service.
- Stakeholder Involvement

These factors could be summarised within their correspondent sub-stage on the table below:

		Before Use			During Use / Operation		After Use			Beyond Building
		A1 + A3	A2 + A4	A5	B1 - B7		C1	C2	C4	D
		Planning / Design/ Commisioning	Production building products	Transport	Construction	Building related for fabric	User and control system related	Disasembly	Transport of Waste	Disposal	Recycling
Impact / Involvement of	Users of Building	Integrated Planning procedures; User participation; Stakeholders involvement	-	-	-	Accessibility; Adaptability; Health and Comfort; Maintenance; Safety and Security	Health and Comfort; Maintenance; Safety and Security	Hazardous materials, accidents, noise, dust	Noise, traffic, dust	-	
	Neighbourhood	Neighbourdhood participation; Skateholder Involvement	-	Traffic noise	Traffic and noise; Social standards of construction process	Loadings in neighbourhood	Loadings in neighbourhood	Hazardous materials, accidents, noise, dust	Noise, traffic, dust	-	
	Society	Quantity of urban planning process	Social standards / working conditions during extraction and processing of raws materials; And during manufacturing of products; Sourcing of materials; Regional economic and employment effects	Traffic (noise, etc) alongside of the transport routes	Social standards of companies involved; Social facilities on construction site; Stakeholder involvement	Infrastructure; Social affordability and cost efficiency; Stakeholder involvement	-	Hazardous materials, accidents, noise, dust concerning construction workers; Design for easy disassembly	Traffic (noise, etc) alongside of the transport routes	Health aspects of products and components; Design for reuse or recyclability	

Figure 3.2: Social Factor within the built environment

Accessibility:

It is the ability of a space to be entered with ease. According with the BS EN 15643:2021 [80], the assessment of accessibility shall include the following aspects:

- accessibility for people with specific needs
- access to building services

It encourages the sustainable design of the buildings/dwellings, its comfortable approaching routes facilities and the adoption of accessible paths for all needs. This category also encourages the best option design for sanitary spaces inside the buildings/dwellings and its operational comfort zones. Issues in this section focus on use stage but are set up from the design phase being very difficult and costly to change and improve them on a later time within the building process.

Adaptability:

This category means the ability of the object of assessments or parts thereof to be changed or modified to make suitable for a particular use. The assessment of adaptability shall include the following aspects:

- the ability to accommodate individual user requirements.
- the ability to accommodate the change of user requirements.
- the ability to accommodate technical changes.
- the ability to accommodate the change of use.

This category encourages the ease of the demolition process through the design of the building elements. Hence, these factors focus on the end-of-life stage of materials, and they are directly related to the design of the buildings.

Economic factors:

Economic factors are those that intervene within the whole construction project and are representative of the building. Some of the associated costs are the following:

- Acquisition of the ground in which the building will be placed.
- Architectural and engineering project
- Execution budget
- Maintenance and replacement

As mentioned before, they are not part of the scope of this thesis.

3.2.7. Material Ecolabels

Construction products have their own environmental impacts due to raw material extraction, manufacturing process and different transports. Those impacts could be considered prior the product selection at design stages. Unfortunately, this is not usually the case as mentioned before.

There have been some efforts trying to narrow this quantity of data with common documents, called "Environmental Product Declaration" or EPD but there is still a long way to travel if common methods are to be used when evaluating building and its components from different companies and consultancy experts [81].

Furthermore, current regulations permit different level of declarations, having the following types:

- Ecolabel type I: voluntary multi-criteria program. They consist of product declarations based on the ISO 14024 and indicate that the declared product have less impact on the environment due to some environmental criteria considered during its manufacture. The LCA is performed by an independent third party.
- Ecolabel type II, self-declared. They involve self-declaration of environmental impacts from a product that a specific manufacturer performs in order to show how sustainable their product are. It is developed internally within that company and is based on the ISO 14021.
- Ecolabel type III or EPD verified. This type explains the quantification of the impacts of a specific product over its life cycle. In this case, only objective data is shown instead of weighting the environmental performance of a product. So that, comparison could be made against other similar products. They are developed by an independent body and verify by a third party.

Most LCA programs, usually take their environmental data from all these declaration types. Hence, bearing in mind that database and LCA assumptions will be most probably different, it becomes a difficult task compare between different evaluation

The correct assessment will use only EPD or environmental impact information from the sources in which accurate and objective verified data is available. There are some web portals collecting all EPD pretending to have a fairly big "consistent" dataset, but continues innovations and developments make this task almost impossible, having to update the information instantly.

3.2.8. LCA reference benchmarks

Regarding the construction sector, either the existing stock and future developments, there are both RIBA and LETI have set out some benchmarks according to the current "business-as-usual" as well as for the targeted years 2025, 2030 and 2050, following the climate agreements achieved on the Paris 2015 climate change conference COP21 [82].

RIBA started with some targets for embodied and operational carbon on 2019 and then reviewed them [83] resulting on the following benchmarks:

RIBA Sustainable Outcome Metrics	Business as Usual	2025 Targets	2030 Targets	Notes
Operational Energy kWh/m^2/y	120 kWh/m^2/y	< 60 kWh/m^2/y	< 35 kWh/m^2/y	Targets based on GIA. Figures include regulated & unregulated energy consumption irrespective of source (grid/renewables). BAU based on median all electric across housing typologies in CIBSE benchmarking tool. 1. Use a 'Fabric First' approach 2. Minimise energy demand. Use efficient services and low carbon heat 3. Maximise onsite renewables
Embodied Carbon kgCO₂e/m^2	1200 kgCO$_2$e/m^2	< 800 kgCO$_2$e/m^2	< 625 kgCO$_2$e/m^2	Use RICS Whole Life Carbon (modules A1-A5, B1-B5, C1-C4 incl sequestration). Analysis should include minimum of 95% of cost, include substructure, superstructure, finishes, fixed FF&E, building services and associated refrigerant leakage. 1. Whole Life Carbon Analysis 2. Use circular economy strategies 3. Minimise offsetting and use as last resort (accredited and verifiable) BAU aligned with LETI band E; 2025 target aligned with LETI band C and 2030 target aligned with LETI band B.
Potable Water Use Litres/person/day	125 l/p/day (Building Regulations England and Wales)	< 95 l/p/day	< 75 l/p/day	CIBSE Guide G.

Figure 3.3: RIBA Residential targets

On the other hand, London Energy Transformation Initiative (LETI) has also set out some benchmarks for new buildings [84], with special attention to embodied carbon of several building typologies in their transition to net zero carbon buildings. These benchmarks are more aligned with the 2019 RIBA benchmarks and could be summarised as follows:

	Baseline	Best practice 2020	Best practice 2030
Domestic	800 kgCO$_2$/m^2	<500 kgCO$_2$/m^2 Equiv. to 40% reduction over baseline 30% materials from re-used sources 50% materials can be re-used at end of life	<300 kgCO$_2$/m^2 Equiv. to 65% reduction over baseline 50% materials from re-used sources 80% materials can be re-used at end of life
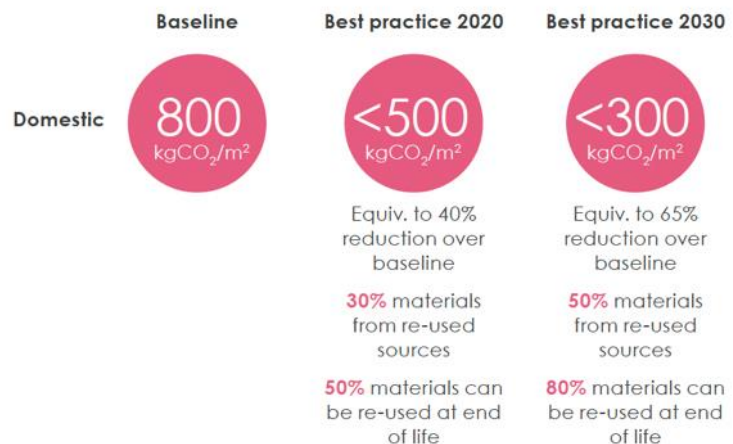
Figure 3.4: LETI Residential embodied carbon targets

However, current figures that could be considered as usual for nowadays domestic buildings would be 1,000 $KgCO_2e/m^2$ (GIA), related to LETI band D. This case would have an operational energy consumption of approximately 60 kWh/m2/year (GIA) and a potable water use averaged in 110 L/p/day.

In addition, the complete life cycle view for embodied and operational impacts could be visualized as follows, for a 60 years of study period considered:
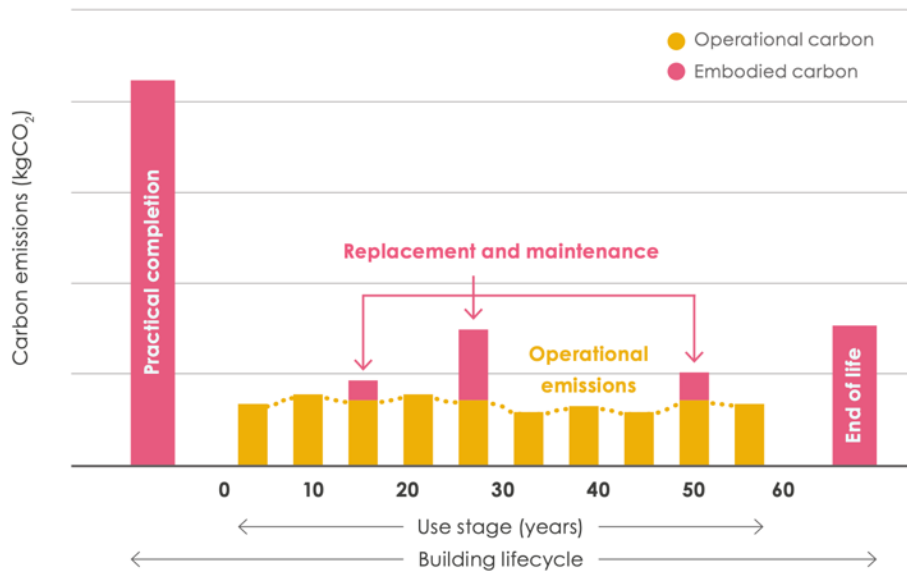
Figure 3.5: embodied & operational impacts throughout the building life span (LETI)

Embodied and operational current targets for very low energy buildings could be summarised as the following graph shows. It could be also mentioned that other European embodied carbon benchmarks are arising since more sustainability concern is already been discussed within local authorities and institutions [85]:
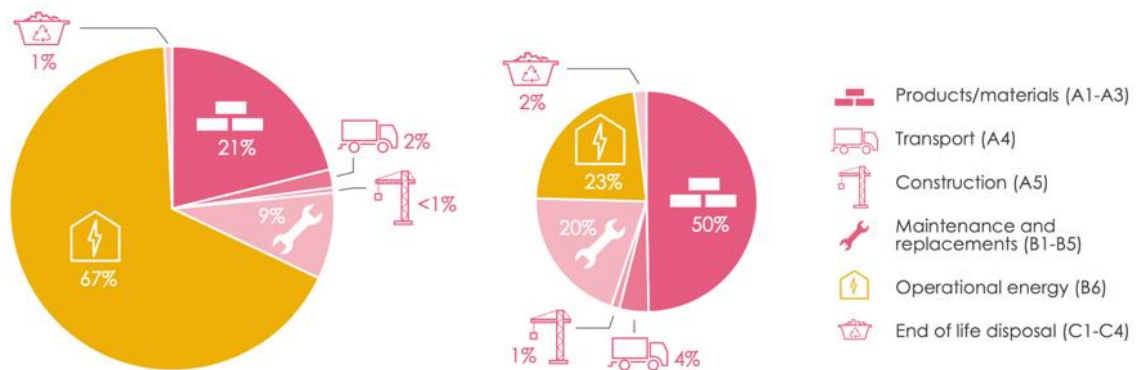
Figure 3.6: Residential medium scale impact benchmarks by LETI design guide

3.3.   Legal Framework

This section does not pretend to be a Standard's literature review but the project framework to have into account within legal procedures in order to achieve a rigorous and solid base for the proposed calculation process and method.

This thesis has identified an extensive legal framework in which it is focused and referred. The research is aware of the current standards related to the field's wide topic which could be defined as sustainability in domestic construction. More specific European LCA framework has also been approached in detail.

For the purpose of this doctoral thesis both European Directive 31/2010 and EN 15978:2012 [3] are of vital importance due to their direct relationship with the building regulation in terms of energy consumption and CO_2 emissions of buildings within its Life cycle calculation process.

Once sustainability has been defined and framed within the regulations and commissions, the following summary is presented in chronological order from world-wide standards to country-specific regulations. It gives a hint of the legal boundaries in which the proposed work will be focusing and in line with.

3.3.1. World-wide Regulations

3.3.1.1.   International Organization for Standardization (ISO)

There is a few ISO standards referring to sustainability in building construction and more specifically to Life Cycle Assessment performance and calculation methodologies.

a) *ISO 15392:2019 Sustainability in Building and Civil Engineering Works (SBCEW) - General Principles*
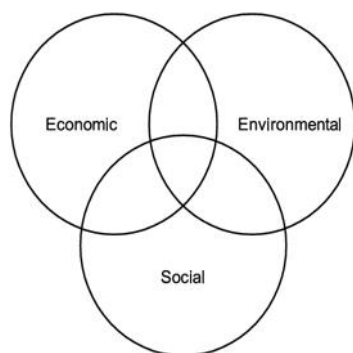
Figure 3.7:Primary aspects of sustainability

Sustainable development of buildings and other construction works brings about the required performance and functionality with minimum adverse environmental impact, while encouraging improvements in economic and social (and cultural) aspects at local, regional and global levels.
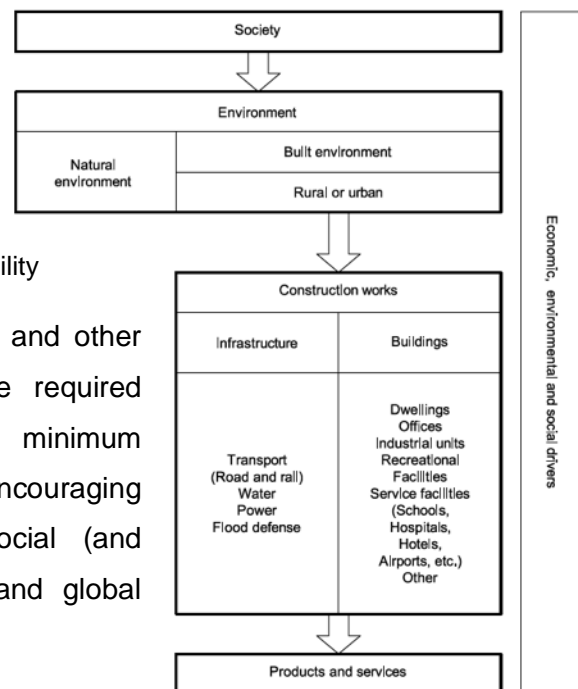
Figure 3.8: Requirements posed to the built environment,

- Global thinking and local action
- Holistic approach

b) *ISO/TS 21929-1(2011): Sustainability in Building Construction (SBC)- Sustainability Indicators. Part 1: Framework for the development of indicators and a core set of indicators for buildings*

ISO 21929-1:2011 establishes a core set of indicators to take into account in the use and development of sustainability indicators for assessing the sustainability performance of

new or existing buildings, related to their design, construction, operation, maintenance, refurbishment and end of life. Together, the core set of indicators provides measures to express the contribution of a building(s) to sustainability and sustainable development. These indicators represent aspects of buildings that impact on areas of protection related to sustainability and sustainable development.
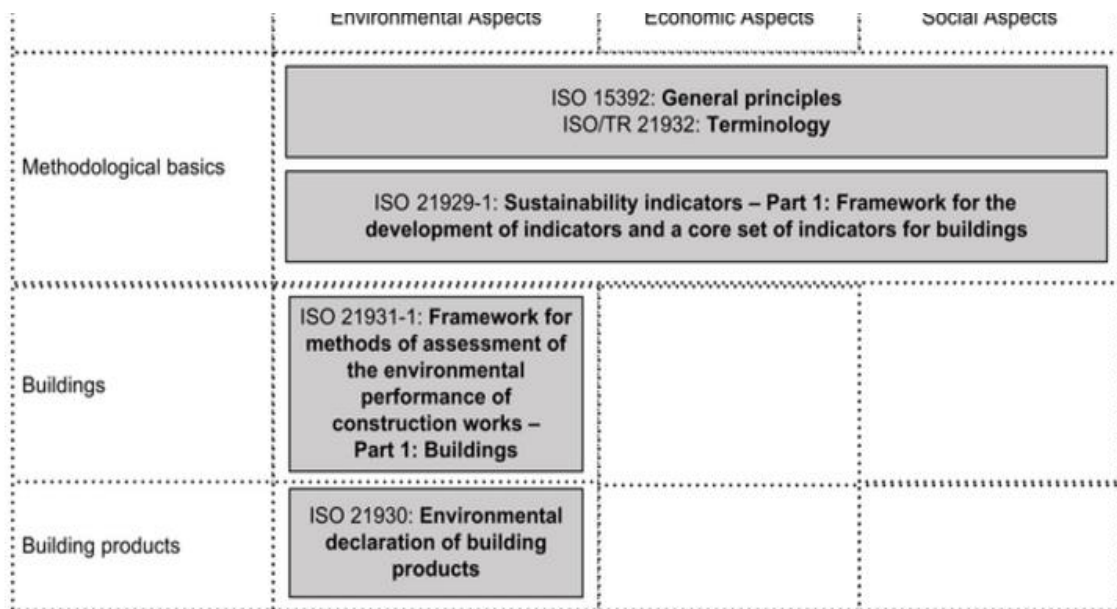
Figure 3.9: Suite or related International Standards for sustainability in construction, from ISO 21929-1

The object of consideration in ISO 21929-1:2011 is a building or a group of buildings and the external works within the site (curtilage). This standard follows the principles set out in ISO 15392:2019.

This ISO adapts general sustainability principles for buildings; includes a framework for developing sustainability indicators for use in the assessment of economic, environmental and social impacts of buildings; determines the aspects for consideration when defining a core set of sustainability indicators for buildings; establishes a core set of indicators; describes how to use sustainability indicators; and gives rules for establishing a system of indicators.

ISO 21929-1:2011 does not give guidelines for the weighting of indicators or the aggregation of assessment results.

c) *ISO 21930(2017): SBCEW-Core Rules for Environmental Product Declarations of Construction Products and Services*

This International Standard provides the principles and requirements for type III environmental declarations (EPD) of building products. It contains specifications and requirements for the EPD of building products. Where this International Standard contains more specific requirements, it complements ISO 14025 for the EPD of building products.

The overall goal of environmental declarations is to encourage the demand for, and supply of, building products that cause less stress on the environment, through communication of verifiable and accurate information on environmental aspects of those building products that is not misleading, thereby stimulating the potential for market-driven, continuous environmental improvement.

d) *ISO/TS 21931-1:2022: SBCEW- Framework for methods of assessment of the environmental, social and economic performance of construction works as a basis for sustainability assessment — Part 1: Buildings.*

The aim of this part of ISO/TS 21931 is to define a framework for methods of assessment for the environmental performance of buildings. In order to be able to communicate information to interested parties regarding the potential environmental impact of buildings, in relation to the concept of sustainability, it is important to understand how the buildings themselves perform in this respect and to benchmark their progress towards achieving improved performance.

The building is the object of the assessment defined in this part of ISO/TS 21931, and this encompasses the building itself, the site and the associated facilities on the site. It is recognized that environmental performance is only one of a number of significant factors in a building's overall performance.

e) *ISO 14000:2015 family: Environmental Management*

This International Standard is applicable to any organization that wishes to:

a) establish, implement, maintain and improve an environmental management system;

b) assure itself of conformity with its stated environmental policy;

c) demonstrate conformity with this International Standard by:

   1) making a self-determination and self-declaration, or

2) seeking confirmation of its conformance by parties having an interest in the organization, such as customers, or

3) seeking confirmation of its self-declaration by a party external to the organization, or

4) seeking certification/registration of its environmental management system by an external organization.

Environmental aspects:

Although there is no single approach for identifying environmental aspects, the approach selected could for example consider:

a) emissions to air,

b) releases to water,

c) releases to land,

d) use of raw materials and natural resources,

e) use of energy,

f) energy emitted, e.g. heat, radiation, vibration,

g) waste and by-products, and

h) physical attributes, e.g. size, shape, colour, appearance.

Consideration should be given to aspects related to the organization's activities, products and services, such as

— design and development,

— manufacturing processes,

— packaging and transportation,

— environmental performance and practices of contractors and suppliers,

— waste management,

— extraction and distribution of raw materials and natural resources,

— distribution, use and end-of-life of products, and

— wildlife and biodiversity.

The structure defined by ISO 14040 [2] is based on the SETAC structure but differs from this one only in the fourth element which is called "Interpretation". The ISO also includes the "Improvement Assessment" but this only one of the many activities which may follow LCA but not part of the analysis.
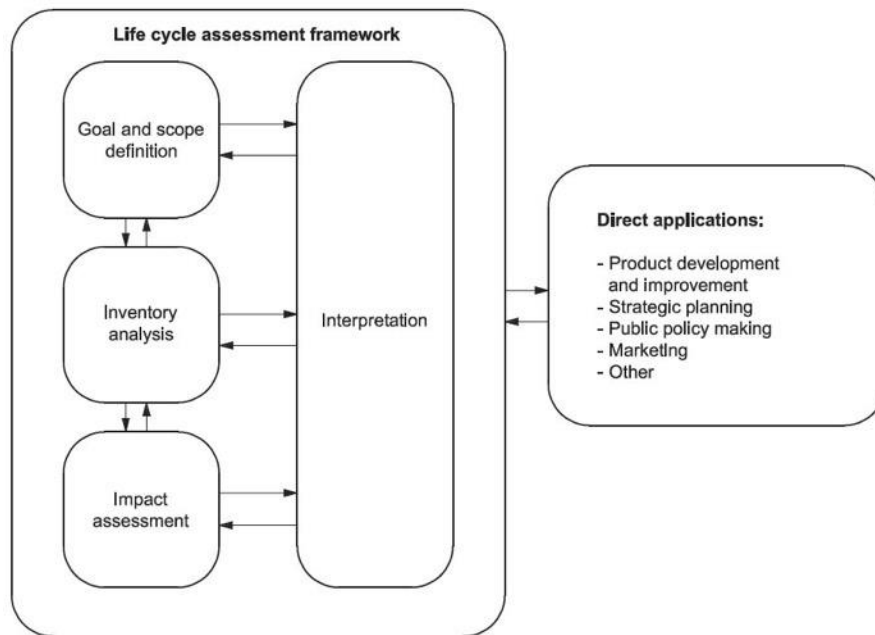
Figure 3.10: Phases of LCA Method According ISO 14040 (2006)

- **Goal and Scope**

The Goal and Scope Definition phase defines the overall objectives, the boundaries of the system under study, the sources of data and the functional unit to which the achieved results refer.

- **Life Cycle inventory**

The Life Cycle Inventory (LCI) consists of a detailed compilation of all the environmental inputs (material and energy) and outputs (air, water and solid emissions) at each stage of the life cycle.

- **Life Cycle Impact Analysis**

The Life Cycle Impact Assessment (LCIA) phase aims at quantifying the relative importance of all environmental burdens obtained in the LCI by analysing their influence on the selected environmental effects.

- **Interpretation of results.**

According to ISO 14040:2006, the general framework of an LCIA method is composed of mandatory elements (classification and characterization) that convert LCI results into an indicator for each impact category, and optional elements (normalization and weighting) that lead to a unique indicator across impact categories using numerical factors based on value-choices.

f) ISO 14020(2000): Environmental Labels and Declaration - General Principles

The overall goal of environmental labels and declarations is, through communication of verifiable and accurate information that is not misleading, on environmental aspects of products and services, to encourage the demand for and supply of those products and services that cause less stress on the environment, thereby stimulating the potential for market-driven continuous environmental improvement.

g) ISO 15686 (1-11) Building and Constructed Assets-Service Life Planning

The Service Life Planning series involve the following parts:

- Part 1: 2011 - General principles and framework

- Part 2: 2012 Service life prediction procedures

- Part 3: 2002 Performance audits and reviews

- Part 4: 2014 Performance audits and reviews

- Part 5: 2017 Life-cycle costing

- Part 6: 2004 Procedures for considering environmental impacts

- Part 7: 2017 Performance evaluation for feedback of service life data from practice

- Part 8: 2008 Reference service life and service-life estimation

Figure 3.11: relationship between parts of ISO 15686 and service life planning, from ISO 15686-1,

- Part 9: 2008 Guidance on assessment of service-life data [Technical Specification]

- Part 10: 2010 When to assess functional performance

- Part 11: 2014 Terminology

ISO 15686-1:2011. This part of ISO 15686 specifies the general principles of service life planning of a building or other constructed asset and presents a framework for undertaking such service life planning. These general principles can also be used to make decisions on maintenance and replacement requirements. It serves as a guide to other parts, including general principles to be applied. Together, they provide requirements and guidance on the estimation or prediction of the service life of a building's components, which contribute to the service life of the building.

ISO 15686-2:2012 specifies principles and procedures that facilitate service life predictions of building components. It provides a general framework, procedures and requirements for conducting and reporting such studies, but does not describe specific test methods. It may also be used as a checklist for assessing completed service life prediction studies.

ISO 15686-3:2002 is concerned with ensuring the effective implementation of service life planning audits and reviews. It describes the approach and procedures to be applied to pre-briefing, briefing, design, construction and, where required, the life care management and disposal of buildings to provide reasonable assurance that measures necessary to achieve a satisfactory performance over time will be implemented.

ISO/TR 15686-4:2014 describes the data required to undertake service life estimation. This is primarily intended to define the data relating to service life that may be required in computer models. The formatting of such data for inclusion in calculation of models is presented in accordance with ISO 12006 (all parts).

ISO 15686-5:2017 specifies procedures for performing life-cycle cost analyses of buildings and their parts. These assessments take into account cost or cash flows, i.e. relevant costs (and income and externalities if included in the agreed scope) arising from acquisition through operation to disposal. This assessment typically includes a comparison between options or an estimate of future costs at portfolio, project or component level. The assessment is over an agreed period of analysis, which can be a time frame that is less than the full life-cycle of the constructed asset.

ISO 15686-6:2004 specifies how to assess at the design stage, the potential environmental impacts of alternative designs of a constructed asset. It identifies the interface between environmental life-cycle assessment and service life planning.

ISO 15686-7:2017 provides a generic basis for performance evaluation for feedback of service life data from existing buildings, including a definition of the terms to be used and

the description of how the (technical) performance can be described and documented to ensure consistency.

ISO 15686-8:2008 provides guidance on the provision, selection and formatting of reference service life data and on the application of these data for the purposes of calculating estimated service life using the factor method. It does not give guidance on how to estimate either the modification part or the values of factors A to G, using the given reference in-use conditions and the object-specific in-use conditions.

ISO/TS 15686-9:2008 gives guidance and provides a framework for the derivation and presentation of reference service life data. In response to market demand, manufacturers and producers can develop, voluntarily, service life declarations for use in service life planning, according to this part of ISO 15686 and ISO 15686-8.

ISO 15686-10:2010 establishes when to specify or verify functional performance requirements during the service life of buildings and building-related facilities and when to check the capability of buildings and facilities to meet identified requirements using procedures for establishing scales for setting levels of functionality or assessing levels of serviceability for any type of facility and any gaps that may exist between demand and supply profiles.1) ISO 15686-10 is applicable to the use, management, ownership, financing, planning, design, acquisition, construction, operation, maintenance, renovation and disposal of buildings and other constructed assets.

ISO 15686-11:2014 provides a compilation of the terms and definitions of concepts that have been standardized to establish a vocabulary applicable to the aspects of both the construction and use of a building or civil engineering works and the service life planning of the same.

3.3.2. European Standards

3.3.2.1. European Directive

Energy Performance of Building Directive 2010/31/EU:2010 (EPBD recast):

The Energy Performance of Building Directive [71] includes environmental information in energy certificates, particularly CO_2 emissions and reducing these impacts in the building sector requires appropriate evaluation method allowing the guidance for efficient operation and management of buildings (design performance) and methods and tools to evaluate the most cost effective actions for energy saving and reduced environmental impact over the whole Life Cycle of a building [86].

The targets, according to this directive, for 2020 were the following:

- 20% reduction of total GHG emissions
- 20% energy efficiency improvement
- 20% of energy consumption should come from renewable resources.

The Article 9 of the Directive set up the direction toward building construction should point in order to get Zero-energy Buildings and the deadlines to get those achievements:

"Towards NEARLY ZERO-ENERGY BUILDINGS"

a) by 31 December 2020, all new buildings are nearly zero-energy buildings; and
b) after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings.

This Directive, on its Article 24 states that all Member States must establish a method to certify the energy performance of buildings. Energy Performance Certificates (EPCs) have been adopted to demonstrate the energy performance of the assessed building, and its relation to the minimum baseline targets. The certificates are used to allow building users and owners to compare the performance and understand the building's impact on the environment.

3.3.2.2.   CEN TC 350

Figure 3.12: Building regulations related to LCA, from 15643:2021, figure 2

3.3.2.3.   EN 15643:2021: Sustainability of Construction Works (SCW) – Framework for assessment of buildings and civil engineering works.

a) *Other than environmental factors.*

EN 15643: 2021 supersedes the old 15643-1 to 5, and provides the general principles and requirements, expressed through a series of standards, for the assessment of buildings in terms of environmental, social and economic performance taking into account technical characteristics and functionality of a building. The assessment will quantify the contribution of the assessed construction works to sustainable construction and sustainable development.

The framework applies to all types of buildings and it is relevant for the assessment of the environmental, social and economic performance of new buildings over their entire life cycle, and of existing buildings over their remaining service life and end of life stage.

The European Standards developed under this framework do not set the rules for how building assessment schemes may provide valuation methods. Nor do they prescribe levels, classes or benchmarks for measuring performance.

The interpretation and value judgments of the results of the assessment are not within the scope of this European Standard.

This standard also provides the specific principles and requirements for the assessment of environmental, social and economic performance of buildings taking into account technical characteristics and functionality of a building:
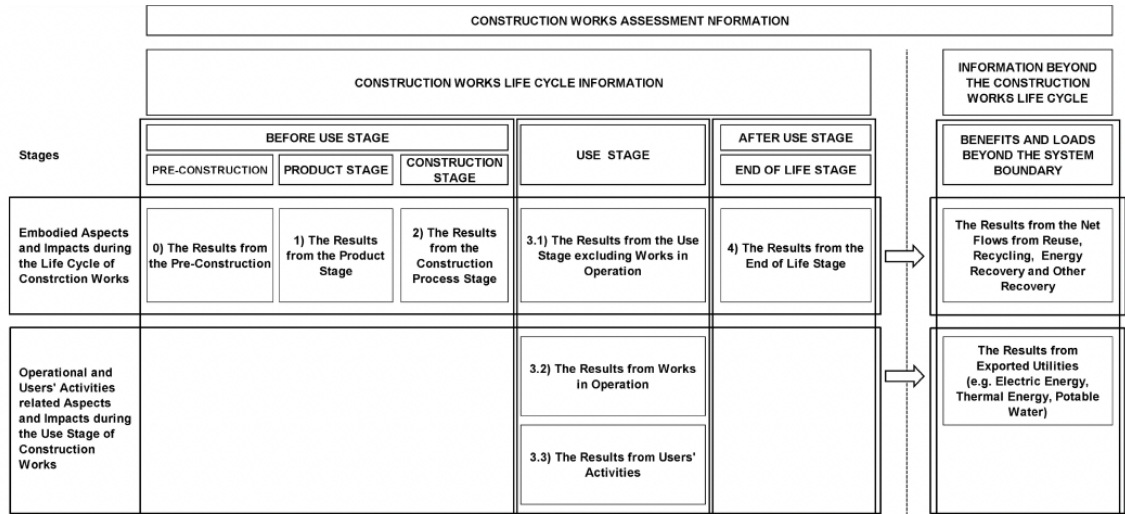
Figure 3.13: Building Life Cycle stages information, from EN 15643:2021, figure 5

b) Environmental Performance.
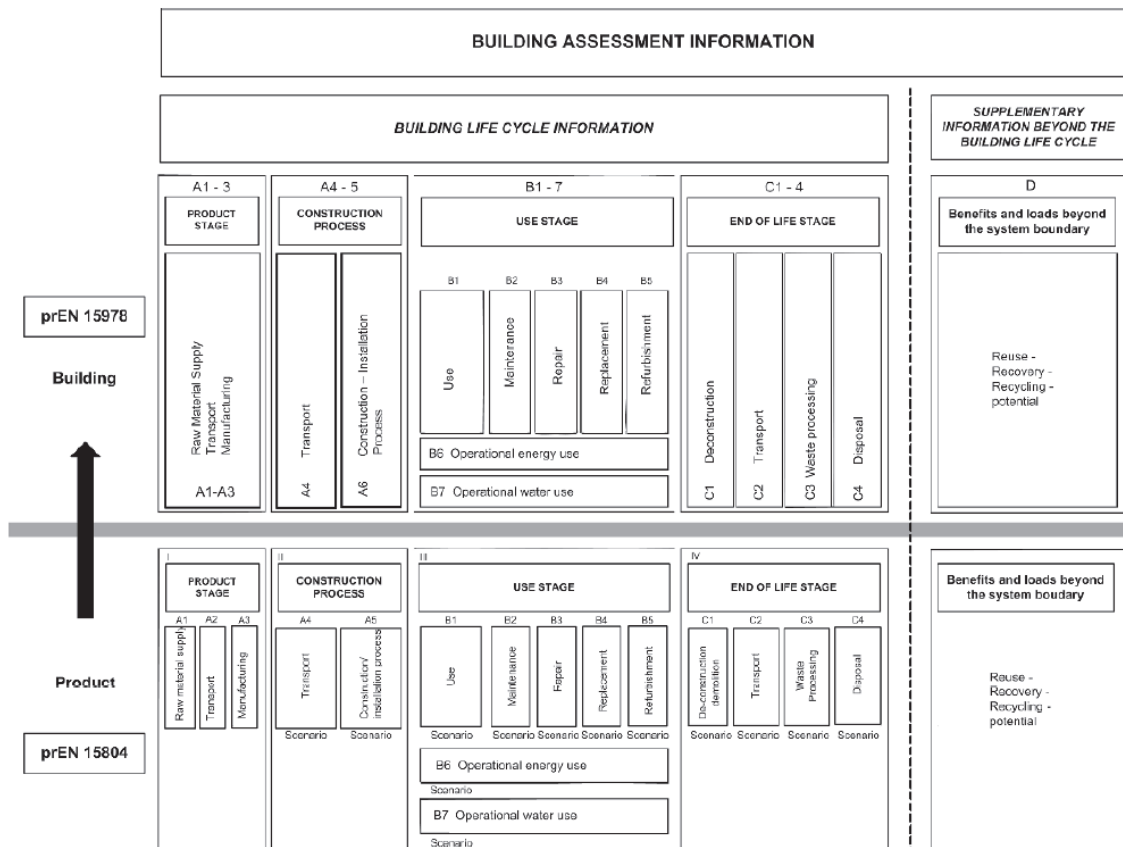
Figure 3.14: Building Life Cycle stages information, from EN 15643-2, figure 3.

c) *Social Performance.*

This Standard describes the following social performance categories:

a. accessibility;

b. adaptability;

c. health and comfort;

d. impacts on the neighbourhood;

e. maintenance;

f. safety and security;

g. (sourcing of materials and services);

h. (stakeholder involvement);

d) *Economic Performance.*

The economic performance assessment of a building addresses the life cycle costs and other economic aspects, all expressed through quantitative indicators. It excludes the economic risk assessment of a building and return on investment calculations.

The following standards (EN 15978, EN 16309 and EN 16627) [3] provide the calculation method based on the specific principles and requirements for the assessment of environmental, social and economic performance of buildings previously mentioned.

3.3.2.4.   EN 15978:2011. Environmental Performance of buildings. Calculation Method [3].

The standard gives:

- the description of the object of assessment;
  - General description
  - Functional equivalent
  - Reference Study Period (RSP)
- the system boundary that applies at the building level for each sub-stage;
  - Operational Energy use (B6):
- the procedure to be used for the inventory analysis;
- the list of indicators and procedures for the calculations of these indicators;
- the requirements for presentation of the results in reporting and communication;
- the requirements for the data necessary for the calculation;

3.3.3. UK related Standards

3.3.3.1. Energy White Paper 2007

The target was set up by the UK government of cutting the UK's carbon dioxide emissions by some 60% by about 2050, with real progress by 2020.

3.3.3.2. UK Carbon Plan - Towards Zero Carbon buildings

Zero carbon homes were stated on 2006 and Part-L/Section 6 was then modified.

http://www.designingbuildings.co.uk/wiki/Zero_carbon_homes

In December 2006, the Labour government committed that from 2016 all new homes would be 'zero carbon' and introduced the Code for Sustainable Homes, a code against which the sustainability of new homes could be rated.

This commitment was affirmed in the *"Building a Greener Future: Policy Statement"* in 2007 which proposed progressive tightening of the building regulations to achieve the 2016 goal, first by 25% in 2010 and then by 44% in 2013.

The Labour budget in 2008 announced a further intention that all new non-domestic buildings should also be zero carbon from 2019.

All new homes from 2016 must be Zero Carbon Homes.

a) by 2016: new Homes must meet the Zero Carbon Standard;
b) by 2019 all non-domestic buildings should also be "zero carbon";

3.3.3.3.   Climate Change Act 2009 Scotland

The Climate Change Act 2008 [87] established a long-term legally-binding framework to reduce GHG emissions, committing the UK to reducing emissions compared to the 1990 baseline. It also requires the Scottish Ministers to set annual targets for emissions at least 12 years in advance. In October 2010 the Scottish Parliament passed legislation setting the first batch of annual targets, for the years up to 2029. Targets for 2023-2027 were set in October 2011 and will continue to be set at 5-year intervals.

This Climate Change Act involves the following interim reduction for Scotland:

(a) Scottish emissions should be at least 80% lower by 2050, compare to baseline
(b) Interim target for GHG emissions to be at least 42% lower by 2020, compare to baseline

To drive progress and set the UK on a pathway towards this target, the Act introduced a system of carbon budgets which provide legally binding limits of emissions that may be produced in successive five-year periods, beginning in 2008. The first three carbon budgets were set in law in May 2009 and require emissions to be reduced by at least 43% below base year levels in 2020.

Furthermore, it sets that the Scottish Ministers must ensure that the net Scottish emissions account for the net-zero emissions target year is at least 100% lower than the baseline (the target is known as the "net-zero emissions target"). This "Net Zero" target year is 2045.

Table 3.2: Climate Change (Scotland) Act 2009. Interim reduction targets

Year	Reduction Target
2020	56%
2030	75%
2040	90
2045	100%

3.4.   Conclusions

As it has been stated previously, indicators are the values in which the environmental impacts are measured. For current sustainability standards [2, 71] indicators are many and difficult to understand [72] for non-experts. It becomes very complex to see how the total figure, given by the weighted indicator, that affects to the environment.

For this reason, simple and straight forward global indicators are needed if LCA pretends to become more commonly used analysis by stake holders. It also would need to summarise the indicators units or the proper harmful impacts to the environment. Otherwise, only a couple of them, such as Global Warming Potential (usually measured in $KgCO_2e$) could be slightly understood.

Although a complete LCA of a building is considered a very hard task, environmental impacts from different materials, processes within all stages need to be added, having into account all assumptions considered. Hence, materials specification and quantities should be clearly listed in order to assign environmental impacts to those materials and processes. Then allocate those impacts within the correct stage. EPDs specifications give a good start for the environmental impacts for products, but country specifications or non-mandatory stages considered could be a burden to accomplish when pursuing a more extended LCA of a building.

Environmental legal framework is under continuous revisions and adjustments.

4

CHAPTER 4: ENVIRONMENTAL AND LCA TOOLS

4.1.   Environmental Assessment Tools

Since the primary question of this research, mentioned on Chapter 1, is related to LCA assessment tools, and this project aims to propose a valid calculation tool, a detailed classification of available tools becomes necessary.

-    *To what extent do the **Life Cycle Assessment tools**, designed to evaluate buildings, cover the current needs to achieve the mandatory embodied and operational decarbonisation and optimization objectives?*

This section presents two different approaches to building environmental tools.

The very first approach to environmental tools has been made through the literature consulted about them resulting on a series of summary tables were primary and general information about each tool is indicated. This is explained in more detail on section 4.2.

A second approach has been developed with a practical evaluation presented on section 4.3 and a scoring system for those tools presented on section 4.4., along this chapter. Every tool that was likely to be involved within the LCA of buildings [18], or related to this topic have, has been categorized and analysed from a practical point of view, trying to carry out an analysis or simulation for what they were created for. For this practical analysis, only free or demo versions has been used, that is, without any subscription that many tools need for a full-version performance. It is noted that not using the complete version could have limit the outputs obtained.

In order to categorise these, there are two well-known LCA tools classifications systems. First one presented was made by the Athena Institute [88] and the second was indicated by the International Energy Agency (IEA) - ANEXX 31, within the Energy Conservation for Building Life Cycle [89]. They categorize the environmental tools within different groups depending on the processes they are based and if they are rating or a decision-making tool [42], quantitative or qualitative methods tools [90].

Although classification tables presented below are complete, further study of the most relevant tools for this project have been studied deeply, explained on this chapter.

Limitations on this further evaluation have been stablished, since not all classified tools had direct access to them. Having into account that almost all of them are private developments with great annual fees to have full access, not all tools could be included but the most competent to the specific field of study.

4.1.1. LCA approach

When talking about LCA of building, impact method and indicators are extremely important to be set up prior the analysis, as commented on chapter 3. Moreover, when classifying LCA tools for buildings, the goal need to be also quite clear, since there could be attributional or consequential approaches [91].

Attributional point of view gives back a current "state-of-the-art" of the environmental impact of that specific building, with the actual assumptions made for that assessment. While consequential approach reflects indirect effects due to decisions that could vary the current market of materials or processes. This is, consequential studies become more relevant when trying to account the economic effect when changing the current production system [92].

Bearing in mind the principal aim of the LCA tool, they could be classified more aligned to the attributional or consequential approach, depending on the type of assessment and outcome soughed.

This thesis aims to propose an attributional tool, where specific results for some impact indicators are obtained, having the decision-making power for an earlier improvement on those impacts.

4.1.2. Athena's classification System

The ATHENA classification was introduced by the Athena institute and has three classification levels as explained below:

Table 4.1: ATHENA Classification system

Level	Description	Environmental tool
Level 1	Product Comparison. Information sources.	BEES 3.0* TEAM™*
Level 2	Whole building design. Decision-maker tool.	ATHENA™*, BEAT 2002*, BeCost, EcoQuantum* Envest 2.0* EQUER, LEGEP PAPOOSE
Level 3	Whole Building assessment framework or system.	BREEAM* EcoEffect* EcoProfile* (EkoProfile) Environmental Status Model ESCALE LEED*
Supporting Tools	General Support to design process or other tools	Calener GT* Design Builder*

(*) Tools studied in this research

First level for product-level tools, secod level for complete LCA quantification tools and the third one for rating schemes methodologies.

4.1.3. IEA – Annex31 Classification System

On the other hand, IEA Annex-31 classification has the categories listed below, although some tools have been not mentioned here as they are not essential for this study. The following table also presents the combination of these two classification systems indicated:

Table 4.2: Environmental tools study by IEA-Annex 31 and Athena classification

Class	Description	ATHENA Classification	Environmental tools studied	Type
Class 1	Energy Modelling Software	Supporting Tools	Calener GT Design Builder	Interactive tools (Attributional)
Class 2	Environmental LCA Tools for Buildings and Building's Product.	Level 1	BEES Envest 2.0 LISA TEAM™	Interactive tools (Attributional)
Class 2	Environmental LCA Tools for Buildings and Building's Product.	Level 2	ATHENA™ BEAT 2002 EcoQuantum ECOTEC	Interactive tools (Attributional)
Class 3	Environmental Assessment Frameworks and Ratings Systems	Level 3	EcoEffect BREEAM EcoProfile (EkoProfile) GBTool LEED NABERS	Passive tools (Consequential)
Class 4	Environmental guidelines or checklists for design and building management			
Class 5	Environmental Product Declarations, catalogues and reference information			

As indicated on the previous table, IEA classification has different type of tools, depending on the active or passive interaction of them with the assessor. It also has different classes within the typology of the tool. It has also 2 more categories "Environmental Guidelines or Checklists" and "Environmental Product Declarations" which are not part of the study since they are focused on the product level instead of the building level, which is the core of this project.

Further investigation about these other two categories could be considered for other investigation lines of work as indicated on chapter 8 – discussions.

Classification "Class 1" involves Energy modelling software. That means programs with which we could model how the building performs in terms of energy consumption, gain or loss of energy loads. They have into account the activity for which the building was developed, the climate data for that place, all the U-values of their components (construction elements) and the energy flows of each component inside the building such as HVAC system integrated. These tools do not apply some criteria or indicators for the evaluation. They just apply some algorithms to the input data such as U-values, thickness of layers, heat load, solar hours…etc in order to get some results.

The second level involves quantitative Life Cycle Assessment tools. This means programs with which is possible to perform a complete assessment of a product or building. They use quantitative criteria and indicators that can vary between them in order to use their algorithms and give the results. This criterion depends on the Impact Methods that they are using in which the indicators are set. They do not rate a product or building, and they always need a large database for all products and processes involved within the built environment.

The third class of programs involves rating tools with which are possible to perform a holistic approach to life cycle assessment of a product or building. Then they will weight each criterion in order to get a final conclusion or "rate" of the product assessed. They use descriptive, quantitative and qualitative criteria to perform the evaluation and give a percentage of importance (weighting factor) to each indicator that they assume better for an actual assessment. Those weighting factor vary from one to another and each program update and change them periodically, so the final rate is different depending on the time that the assessment was perform. They may have also their private and own "Impact Method" for the evaluation with different criteria and indicators but always with at least the standardised ones. Expertise of users is needed on each of the building typology or product evaluated, and they usually need from LCA tools to have a complete rate from the quantitative evaluation of the product. In case they don't have these LCA approach, a lower rate or score could be obtained.

4.2.   Literature review of LCA tools

4.2.1. Tools and characteristics considered

Considering the international classification systems mentioned above, regarding those tools indicated on table 4.2, a list of environmental tools has been made, indicating the following characteristics based on the literature reviewed. The tools considered for this study are the following:

Table 4.3: environmental tools deeply analysed

Level	Description	Tool
Level 1	Energy modeling Software - (EMS)	Calener GT Design Builder
Level 2	Life Cycle Assessment tools (LCA Toools)	BEES 3.0 TEAM^{TM} ATHENA^{TM} EcoQuantum EcoEffect ECOTECT EcoProfile BEAT 2002 LISA Envest 2.0
Level 3	Environmental assessment framework tools or rating systems (EAF)	BREEAM GBTool LEED NABERS

The characteristics analysed for each of those tools are the following:

-       What was the primary use for which the tool was created?
-       What kind of building was the targeted when creating the tool?
-       What building typology is possible to assess with that tool?
-       What Life Cycle phases are covered within the possible assessment?
-       Who was the intended final user of the tool?
-       What is the output of that evaluation?

Considering these characteristics, a complete review has been performed with the aim of clarifying the actual "state of art" of these programs when assessing buildings. The review has been summarised on several tables where all programs are listed and ticked on the appropriate box for a quick understand. A tick means that the program is applied for it and a tick in brackets means that the program could be applied for it but was not intended for it from the beginning.

4.2.2. Summary of result from literature review of tools

The results are indicated on the following tables. As indicated before, tools have been analysed within the different levels and categories, and then checked against the six criteria listed above. All results are exposed with three different tables, since one only table didn't cope all of them. For that reason, keys have been used, so tables are a little bit narrower.

Table 4.4: environmental tool study: key

Purpose and building		Type of building assessed		LCA stages		Final users	
N	New	R-SF:	Residential-Single-family	P:	Production	A:	Architects Engineering, Constructors
E	Existing	R-MU:	Residential Multi-family	C:	Construction	PB:	Producer Build products
R	Refurbish	OF:	Office	U:	Use/operational	I:	Investor
P	Product	O:	Other	M:	Maintenance	C:	Consultant
		N/S:	Not specify	DM:	Demolition	RES:	Resident
				DS:	Disposal	FM:	Facilities managers

Table 4.5: environmental tool study: results by primary purpose & building assessed

METHOD	CATEGORY			COUNTRY	DEVELOPER	ENGINE	Primary purpose			Building Assessed			
	EMS	LCA Tool	EAF				N	E	P	E	N	R	P
ENERGY	Calener VYP			Spain	MIMA	Calener	✓			✓	✓		
	DeignBuilder			UK		Solar Energy	(✓)	✓		✓		✓	
QUANTITATIVE	IES-VE			UK	Virtual Env.			✓		✓	✓		
		ATHENA™		Canada	ATHENA	Eco-Calculator		✓		✓	✓	✓	
		BEAT 2002		Denmark	SBI		✓			✓	✓	✓	✓
		BEES 3.0		U.S.A.	NIST	BEES			✓				✓
		EcoEffect		Sweden	KTH		(✓)	✓		✓	✓	✓	✓
		Eco-Quantum		Netherlands	IVAM	Eco-Quantum		✓	(✓)	✓	✓	✓	
		EcoProfile		Norway	NBI				✓	✓	✓		
		ECOTECT		Australia	Autodesk		✓	(✓)		✓	✓		
		Envest 2		UK	BRE	Envest		✓					
		LISA		Australia		LISA		✓		✓	✓	✓	
		TEAM™		France	Ecobilan	TEAM		✓					✓
QUALITATIVE			GBTool	Canada	GBC		✓				✓	✓	
			BREAM	UK	BRE					✓	✓	✓	
			LEED	U.S.A.	US G.B.C.		✓	✓		✓	✓	✓	
			NABERS	Australia			✓	✓		✓	✓		

Table 4.6: environmental tool study: results by building type & LCA stage

METHOD	CATEGORY			Type of building assessed					Phases of Life Cycle							
	EMS	LCA Tool	EAF	R-SF	R-MU	OF	O	N/S	P	C	U	M	DM	DS	RC	RU
ENERGY	Calener VYP			✓	✓	✓	✓			✓	✓	✓				
	DeignBuilder			✓	✓	✓	✓				✓					
QUANTITATIVE	IES-VE			✓	✓	✓					✓	(✓)				
		ATHENA™		✓	✓	✓	✓		✓	✓		✓	✓	✓		
		BEAT 2002					✓									
		BEES 3.0						✓	✓		✓	✓		✓		
		EcoEffect			✓	✓		✓	✓	✓	✓	✓	✓	✓		
		Eco-Quantum		✓			✓		✓	✓	✓	✓	✓	✓		
		EcoProfile		✓	✓	✓					✓	✓				
		ECOTECT		✓	✓	✓			✓	✓	✓					
		Envest 2					✓		✓	✓	✓	✓	✓	✓		
		LISA		✓	✓	✓	✓		✓	✓		✓				
		TEAM™						✓	✓	✓	✓	✓		✓		
QUALITATIVE			GBTool		✓	✓	✓		✓	✓	✓		✓	✓		✓
			BREAM	✓	✓	✓	✓		✓	✓	✓	✓		✓	✓	✓
			LEED	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓		
			NABERS	✓	✓		✓			✓	✓	✓		✓		

Table 4.7: environmental tool study: results by user & output

METHOD	CATEGORY			User								Output
	EMS	LCA Tool	EAF	A	PB	I	C	RES	FM	RS	AT	
ENERGY	Calener VYP			✓	✓	✓			✓	✓	✓	Comparison agaisnt a reference model
	DeignBuilder			✓	✓		✓		✓	✓	✓	Annual energy consumption data
QUANTITATIVE	IES-VE			✓	✓		✓			✓	✓	Annual energy consumption data
		ATHENA™		✓			✓			✓		Environmetnal data through out the stages
		BEAT 2002		✓ ✓	✓ ✓		✓			✓	✓	Energy consumption data
		BEES 3.0		✓	✓		✓			✓		Product environmental data
		EcoEffect		✓		✓	✓			✓		-
		Eco-Quantum		✓	✓	✓	✓			✓	✓	-
		EcoProfile				✓	✓				✓	-
		ECOTECT		✓	✓					✓		Energy consumption data
		Envest 2		✓			✓		✓	✓	✓	Enviromental data of industrial buildings
		LISA		✓	✓					✓		Environmental data of building
		TEAM™		✓	✓		✓			✓	✓	Environmental data of industrial processes
QUALITATIVE			GBTool	✓	✓					✓	✓	Score from -2 to +5
			BREAM	✓		✓	✓	✓	✓	✓	✓	Score: Pass, good, Very Good, Excellent
			LEED	✓	✓	✓	✓	✓	✓	✓	✓	Score: Nothing,Silver, Gold, Platinium
			NABERS	✓	✓	✓		✓	✓		✓	Score: Basic, Green, Bronze, Silver, Gold, Platinium

4.3.   Practical test of LCA tools

Although this section focusses on IEA-Annex 31 level 2 classification, as they are the Life Cycle Assessment tools for complete buildings, in which all three LCA framework steps could be applied, a practical evaluation of a range of the most relevant tools throughout all three IEA classes and Athena's levels have been performed.

For this practical study, all programs have been downloaded, installed and used with the free version available at this time. The following sub-sections present the outputs of this analysis, which has also been converted to a numerical score, based on the user

After having understood what is possible to assess theatrically with each program, and all characteristics when performing the Life Cycle assessment of buildings, there are still some questions such as how easy are those tools to manage, or what grade of expertise is needed, or how long does it take to evaluate a complete building or even how is it possible to know that the results obtained from one of them are always correct. The research primary question has tried to be addressed with this practical evaluation in which the following tools have been tried:

Table 4.8: environmental tool evaluated

SOFTWARE TOOL

EPoB	Calener VYP
	Design Builder
	IES
LCA	TEAM 5.1
	SimaPro 8
	GaBi
	Athena Impact Estimator
	OneClick LCA
Score scheme	EcoHomes

4.3.1. Practical study Goal and Scope

This study aims to clarify the following objectives:

- Test the general manageability and accessibility of those programs.
- Test the accuracy on their impact methodology and their parameters (criteria and indicators) when assessing the life cycle of an existing and new domestic building.
- Test how friendly they are to and the grade of expertise needed to run them.
- Test the clarity of exposition of the results obtained from them.
- Compare results, when possible, across them.

However, there were some important limitations since not all programs have the full version available without paying a huge license. It was needed to test some of them with the demo version with temporary access to the complete database and some others with the demo version and catted database. In both demo cases all the features were available in order to test the programs. Demo version means full version with limited time and in some cases limited acces to database.

This study had full version and complete access to Calener (and LIDER), Athena IE, EcoHomes and IES. Also it had access to full version with limited time to Design Builder and demo version with limited database to Gabi 6, Team 5.1, SimaPro 8. In this last case the demo version was available only to perform the complete tutorial case study which allows to use all features but with a limited database. Therefore, this study involves a qualitatively comparison (same building introduced and results obtained) of Calener, Athena IE, EcoHomes and IES and a quantitative comparison (tutorial demo with full features available) of the rest of the programs which has been taken into account for the conclusions.

This practical test the same complete building has been considered and evaluated. The building used is the typical two-storey "orlit house", extensively used within the UK and particularly in Scotland, as mentioned on previous chapter. Detailed layout and construction elements definitions are not described, since the aim of this theoretical and practical performance do not involve such a detail of those elements.

4.3.2. Energy Simulation tools

Energy modelling tools, as mentioned before, are usually software programmes in which buildings are modelled, representing the climate conditions, in order to get the energy demand of those buildings.

Construction elements are described to get the correct U-values with which the building will be constructed. Following complex calculation, the programme is able to give the results for a established comfort conditions for every month of the year. The following energy modelling software have been deeply analysed:

Table 4.9: Energy Performance Tools

Software	Source	Version available	Period
Calener VYP	http://www.minetur.gob.es/energia/	FULL	N/A
Design Builder	http://www.designbuilder.co.uk/	DEMO	30 days
IES	http://www.iesve.com/software	DEMO	30 days
Ecotect	http://usa.autodesk.com/ecotect-analysis/	None	N/A

Deep analysis of each one of them is presented below. Further analysis, including social and economic aspects will be further investigated during this chapter. This deeper evaluation considers the following KPIs for every environmental tool evaluated:

- Description
- Data requirement
- Assessment criteria
- Scoring/weithing system
- Present Status
- Key factors

4.3.2.1.   Calener VYP

This program consists on the Energy Efficiency Qualification of houses or small industrial buildings. This is the official software tool for energy declarations in Spain.

Before introducing the project into Calener, it needs to have been evaluated and accepted by LIDER which just verify that the building meets the actual construction regulations regarding the U-thermal values and techniques for construction (CTE-Building Technical code). LIDER compares the building is being evaluated against a hypothetical one that meets the minimum of the actual regulations and climate specification for that location.

Once the project has been accepted and meets the regulations of construction then it can be loaded into Calener for its energy assessment during the Operational stage. It was not possible to complete the test (get the energy demands results) because that program does not let you perform the assessment with building that does not get the minimum score of the current regulations. This means that some old buildings are not possible to assess with Calener.

Data requirement:

General Location of the house is going to be evaluated from a list of cities from different regions in Spain. Materials and construction elements used. Human activity, HVAC facilities and appliances.

Figure 4.1: LIDER screenshot. Inputing general info when performing the practical evaluation

Assessment Criteria:

The criteria is the comparison against a virtual model with the same geometry but minimum U-values for thermal evaluation.Primary energy usage regarding the operating stage of houses and small industrial buildings and CO2 emissions due to the activity.

Scoring/weighting System:

The qualification index of Energy Efficiency is given by RD 47/2007 and its value goes from A (the best) to G (the worst).

Present status: Calener VYP version 12/06/2013. Link to website:

http://www.minetur.gob.es/energia/desarrollo/eficienciaenergetica/certificacionenergetica/documentosreconocidos/programacalener/paginas/documentosreconocidos.aspx

Figure 4.2: LIDER description of an external wall

Key Factors: It is a very intuitive and easy to use software. It generates the primary energy used and CO_2 emissions from a house with a long database about the most used construction elements in Spain. It covers all regions in Spain or lets the introduction of other climate data in order to use it for different cases. It does not let you evaluate the building if it does not meet the minimum requirements of the construction regulations regarding the U-values and techniques.

4.3.2.2.   Desing Builder

The Design Builder software is an advanced graphical user interface that has been specially developed to run Energy Plus simulations. For UK and Republic of Ireland users the Design Builder interface can also be used to produce Energy Performance Certificates (EPCs) and to show compliance with the Building Regulations. It provides a range of environmental performance data such as: annual energy consumption, maximum summertime temperatures and HVAC component sizes.

It is based on the most popular features and capabilities of BLAST (Building Loads Analysis and System Thermodynamics) and DOE-2 (program from the U.S. Department of Energy) but also includes new simulation capabilities such as time steps of less than an hour, modular systems and plant integrated with heat balance-based zone simulation, multizone air flow, thermal comfort, and photovoltaic systems.

The software comes with UK NCM for the EPBD databases and also equivalent ASHARE construction, activity and schedule data. Data templates allow you to load common building constructions, activities, HVAC & lighting systems into your design by selecting from drop-down lists.

Data requirement:

General Location of the house is going to be evaluated from a list of cities from different regions in the world. Materials and construction elements used. Human activity, HVAC facilities and appliances. The evaluator needs to develop the 3D model of the building with materials and construction elements previously defined.
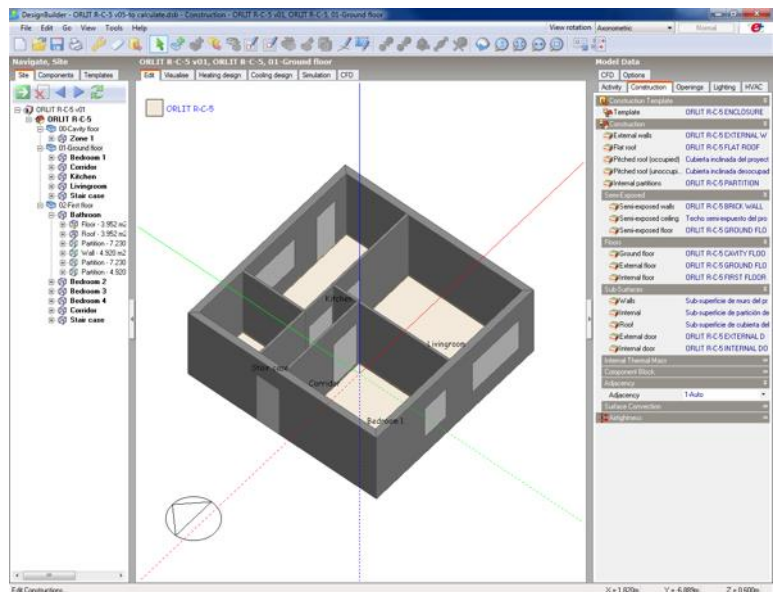
Figure 4.3: DB screenshot. Orlit house analysed, 3D view

Assessment Criteria: the criteria are based on the calculation of the Energy Plus program, that merges BLAST and DOE-2 and takes the data from the UK NCM database included in the program for UK.

Scale of assessment:

- Calculating building energy consumption.

- Evaluating facade options for overheating and visual appearance.

- Thermal simulation of naturally ventilated buildings.

- Daylighting - models lighting control systems and calculates savings in electric lighting.

- Visualisation of site layouts and solar shading.

- Calculating heating and cooling equipment sizes.

- Embodied carbon and energy consumption calculation.

Scoring/weighting System: The calculation allows the evaluator to provide a good quality EPC and Part-L2 service.

Present status: Design Builder v4.2 released. The program includes the latest SBEM v.5.2. required for EPCs and Part-L2 2013 in Wales.

Key Factors: It needs an expert user for running the program. The 3D modelling is very intuitive and easy to use letting the user import CAD plans for an easier completion. It generates the primary energy used and CO_2 emissions from a building with a long database about the most used construction elements. It also lets to modify or generate new elements into the database.

It covers almost regions in the world or lets the introduction of other climate data in order to use it for different cases.
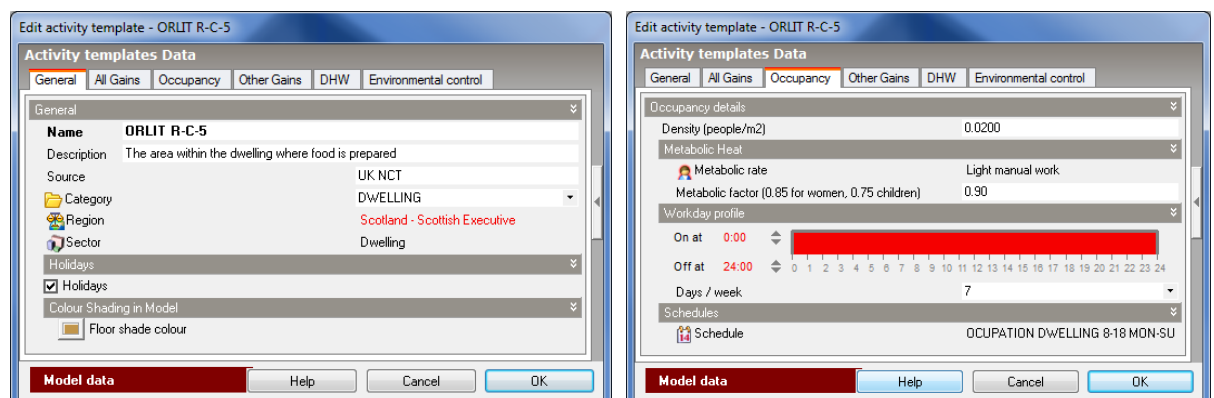
Figure 4.4: DB screenshots. Inputting activity templates for the building evaluated.

4.3.2.3. IES-VE

IES –VE (Integrated Environmental Solutions – Virtual Environment) is a modular software allows the calculation of global energy performance of buildings. It allows the user to calculate the energy demand, HVAC diagram and indoor air quality pf a wide range of buildings with a 3D model of the building. It integrates plug-in for other different programs and BIM characteristics.

It offers a comprehensive suite available for calculation energy performance of buildings. Investigate suitable bioclimatic strategies even before a line has been drawn, and connect from SketchUp™ or BIM packages.

Data requirement:

General Location of the house is going to be evaluated from a list of cities from different regions in the world. Materials and construction elements used. Human activity, HVAC facilities and appliances. The evaluator needs to develop the 3D model of the building with materials and construction elements previously defined. This model could be imported from Sketch-up or created from .dxf 2D draws.
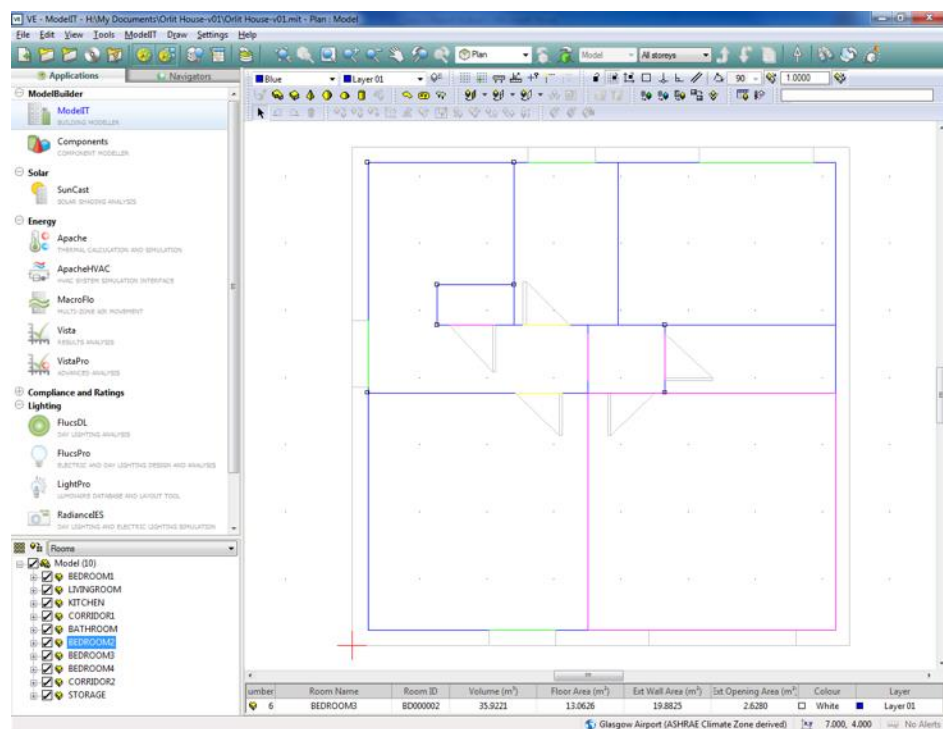
Figure 4.5: IES-VE screenchot. Layout of the Orlit House evaluated

Assessment Criteria: the criteria is based on the calculation of the IES modular program. It has a database included in the program for UK regulations and connection with other LCA programs such as LEED, and BREEAM.

Scale of assessment:

- Energy and carbon calculating.

- Solar calculation. Visualisation of site layouts and solar shading

- Thermal simulation of naturally ventilated buildings.

- Daylighting - models lighting control systems and calculates savings in electric lighting.

- Calculating heating and cooling systems.

- Impact assessment.

Scoring/weighting System: she calculation allows the evaluator to provide a good quality EPC and Part-L2 service.

Present status: IES has launched several plug-in tools for the impact assessment of buildings that could be adopted with Autodesk software.
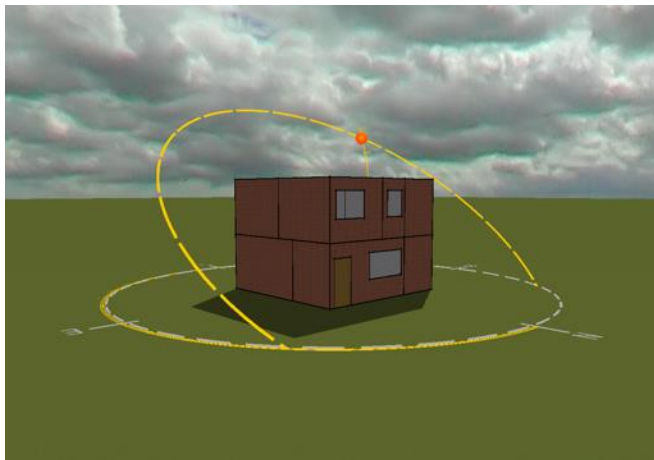
Figure 4.6: IES-VE screenshot. 3D view with sun path

Key Factors:

Is a quite user-friendly program for the 3D modelling and climatic characteristics. Although it has a wide range of examples for the HVAC systems, all of them are "air" conditioning. So it makes difficult to recreate old buildings. Very friendly interface and modules connections. Very good integrated the 2D drawings and 3D modelling programs.

4.3.3. LCA tools

The definition of building performance currently varies according to the interest and skill bases of the parties involved in the building development [93]. Environmental performance assessment has emerged as a major issue in the construction industry. [76] and is becoming even an even bigger concern now that there are significant environmental targets to achieve relating to fossil fuel consumption, CO_2 emissions etc. [1, 87, 94]. Building performance assessment is addressed in a variety of ways including the use of complex LCA software tools which evaluate the environmental impact. These tools use large volumes of inputs and criteria and so a single LCA tool that satisfies all the needs of stakeholders is no easy task [76].

Environmental design parameters need to be considered as early as possible in the assessment process. If they are not dealt with at the outset and during the appraisal stage of a project, later alterations to the brief will cost money, cause time delays and promote friction within the design team [95]. This should be taken into account in order to minimise environmental damage, potentially maximise the specification of low embodied energy materials and reduce remedial costs. Currently environmental performance tools tend to be applied at a stage when it is too late to consider any changes [96]. In addition, the majority don't include end-of-life, financial and social aspects in their evaluation framework due to the already complexity of the assessment [76].

On this second level the following tools have been analysed:

Table 4.10: LCA environmental Tools analysed

Software	Source	Version available	Period
TEAM 5.1	http://ecobilan.pwc.fr	DEMO	N/A
SimaPro 8	http://www.pre-sustainability.com/simapro	DEMO	30 days
GaBi 6	http://www.gabi-software.com/uk-ireland/index/	DEMO	30 days
Athena Impact Estimator	http://www.athenasmi.org/	FULL	30 days
OneClick LCA	https://www.oneclicklca.com	FULL	N/A

4.3.3.1.   TEAMS 5.1

TEAM™ 5.1. is a professional software tool for evaluating the life cycle environmental and cost profiles of products and technologies, including buildings. The software is modular, with over 600 modules.

By linkages to a comprehensive process and material database, TEAM™ tries to carry out a Life Cycle Assessment (LCA) compliant with current methodology standards options.

TEAM is accompanied by an extensive LCA database on products, called DEAM, which the user cannot modify, but add new processes.

Data requirement:

It does not give the possibility of election of the location from a list since it doesn't use climate information on the evaluation.

The program requires the input of all processes involved in the building development. It could be as detailed as desired. The main diagram is clear with the building stages but inside each one it need to have all processes that take part of a building life which could be a very heavy duty as well as difficult to describe every material used and their process.
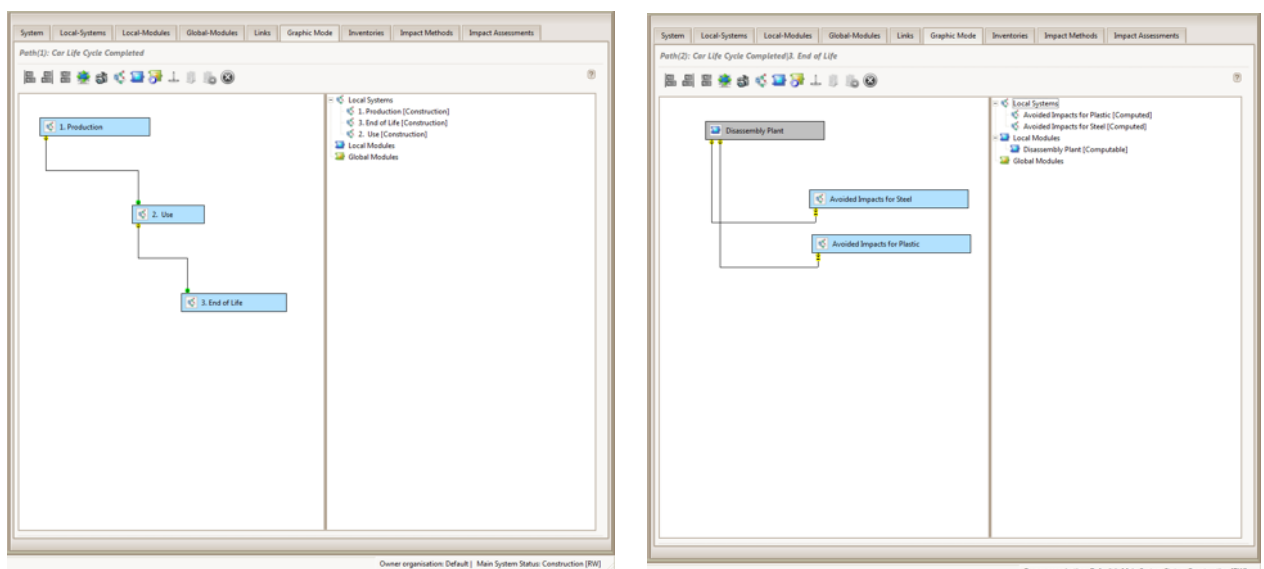
Figure 4.7: screenshot of TEAM 5.1. when performing practical test.

Assessment Criteria:

The criteria in TEAM could be chose from various Impact Methods, being the most complete, in particular, the methods recommended in French standards for environmental labeling BPX 30-323 established by the ADEME-AFNOR platform as part of the environmental labeling of consumer goods.

Scale of assessment: It assesses all processes that have been introduced in the diagram. They can be more or less detailed depending on how accurate the assessment is going to be.

It doesn't divide the stages of the building by itself but with the main processes the evaluator take into account. Then it can give the output of all of them or individually.

Scoring/weighting System:

After specifying all processes involved in the assessment, TEAM breaks them down into their respective materials for the purpose of applying the LCI databases. Then the results show the absolute inventory with impact measures in a tabular format is possible to export.

Present status: TEAM 5.1 is been used for this study, although it has been recently defined the version 5.2.

Key Factors:

No very good performance for buildings. It has a complex matrix design and a weak interaction between building and evaluator.

4.3.3.2.   SimaPro 8

SimaPro provides a professional tool to collect, analyse and monitor the sustainability performance of products and services. With SimaPro, it is possible to model and analyse complex life cycles in a very transparent way, measure the environmental impact of the products and services across all life cycle stages and identify the hotspots in all aspects of your supply chain, from extraction of raw materials to manufacturing, distribution, use, and disposal.

As some of the others software analysed, SimaPro is been thought more for industry processes than for building construction systems. The built environment is still hard to perform with such a LCA software like this. The LCA software SimaPro is developed by "PRé Consultants" in the Netherlands.

Data requirement: it let you briefly introduce the project and scope of it. It doesn't use the climate info for energy performance. But it has a massive database of materials and products.

The user needs to input all processes and systems involved and the energy needed for each of them. In this aspect, for a complete Building LCA would be a huge effort and time consuming
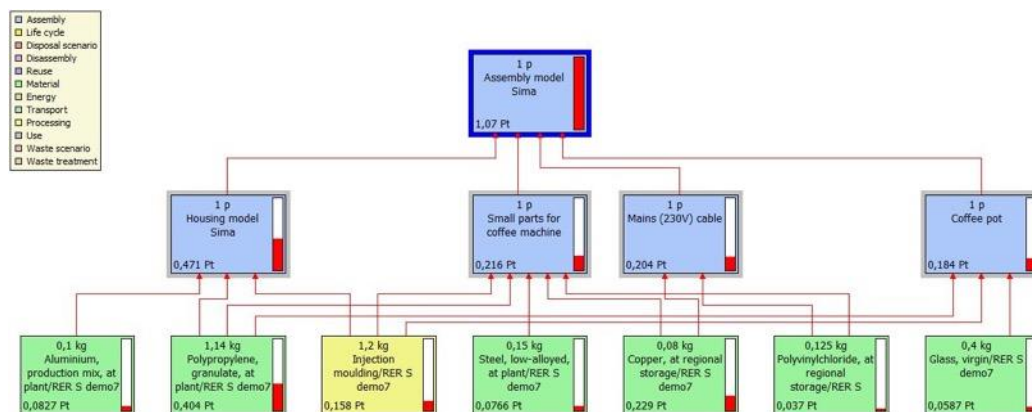
Figure 4.8: SimaPro 8 screenshot when performing the practical test. Graphic flow of impacts

Assessment Criteria:

SimaPro has a few different impact methods for the assessment that the user may apply. The default one is ReCiPe Endpoint, but it lets the opportunity of changing it or even personalize a own one with its own weighting factors.

Scale of assessment:

It doesn't give a final score of the assessment or final rate. It gives the environmental data regarding the impact method used in a very easy graphic way, letting the user comparisons between the different stages and also compare against same product with light modifications in order to be able to choose the best solution of them for the period selected in scope of the project.

SimaPro clearly expose the three stages of the life cycle assessment: characterisation, normalisation and weighting. It is easy to understand the environmental outputs from anyone of those steps and compare the data across them.

Scoring/weighting System: ut depends on the impact method used for the assessment. It varies from one to another.

Present status: the version used for this study was SimaPro 8 which is the most recent version.
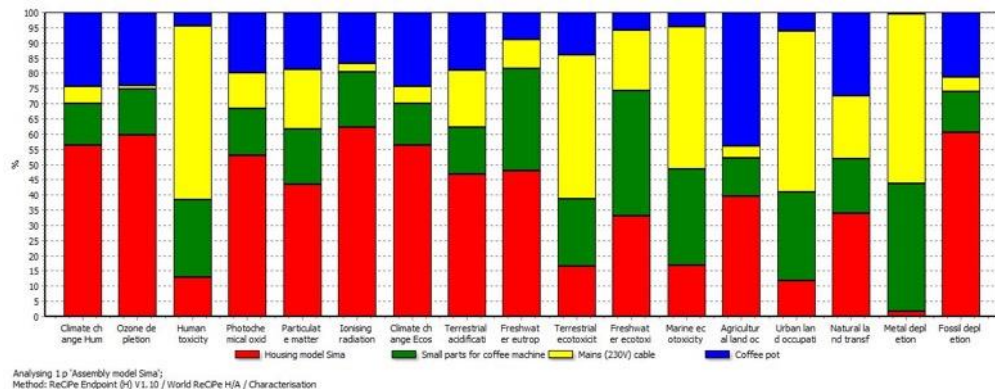
Figure 4.9: SimaPro 8 screenshot when performing the practical test. Impact indicators percentage impacts allocated to each material.

Key Factors:

It needs a very expert user for running the program. The main diagram could be very complete but a lot of features are required to control in order to get a sound use of the program.

The main diagram of the assessment is very intuitive and easy to use. It also lets the user customize some features for a better comprehension of the assessment during all stages that are been analysed such as the hotspots within all the chain or the less environmental parts of it.

4.3.3.3.   GaBi 6

This program was created for LCA of industry processes or, in the built environment, very repetitive construction methods. The Software is more for engineering processes than for architectural matters since it is focused on energy performance and foot print, avoiding any other particular issue within the built environment.

GaBi models every element of a product or system from a life cycle perspective. It is developed by "PE International" and the University of Stuttgart and it consists on the calculation of any process involved in the assessment with its own database or a customized one. Also it lets the user to perform environmental products declarations.

Data requirement:

In order to perform a LCA with this program it is needed a database with every single material used for the building. The user cannot add or modify any materials to the own database, but import others such as Eco-invent or an extended GaBi one. Also the user needs to specify the energy consumption of any process or system created.

For a very complete analysis it must have all processes involved in the building life, detailing it as much as possible. So the main diagram will be huge and the calculation step very heavy.

GaBi allows to model any process chain, by describing a specific production technology or service with the input and output flows, linking it to others if suitable.

Assessment Criteria:

It has the possibility to choose between different impact methods such as Impact 202, ReCiPe, TRACI, CML 2001, being the last one the default one.

It also gives you the possibility of creating an own one and weighting factors personalized.

Scale of assessment:

It doesn't give a final score or rate of the assessment. It gives you the environmental information of the processes and products used on the LCA. It gives you the results in tables and it is possible to export the results to excel format.

Scoring/weighting System:

The one described on the impact method used as criteria for the evaluation.

Present status: the version assessed is GaBi 6, released on 2012

It is possible to get a Demo, cost-free version valid for 30 days:

http://www.gabi-software.com/downloads/

Key Factors:

The program has an intuitive main diagram interface. Easy to create and modify processes.

The problem comes with the database, that needs to be a very complete one.

It is mainly used for industrial processes and not for a LCA of buildings which would make it very long and difficult to link all systems involved.

4.3.3.4.   Athena Impact Estimator

Athena was developed by Athena Sustainability Institute in 2000. It is a practical, easy-to-use software tool that provides environmental data for the project evaluated about materials used and most of the construction assemblies design in North America. Its primary use thought was an environmental assessment tool for building materials and design.

Data requirement:

The required data is brief general description and selection of typical assemblies or specific quantities of individual products.

The location is selected from a list of North American cities. So if the project evaluated is not within those listed, the most approximate in terms of climate. The program take the environmental data from TRACI database merging it with the transport information and average energy costs of the selected city.
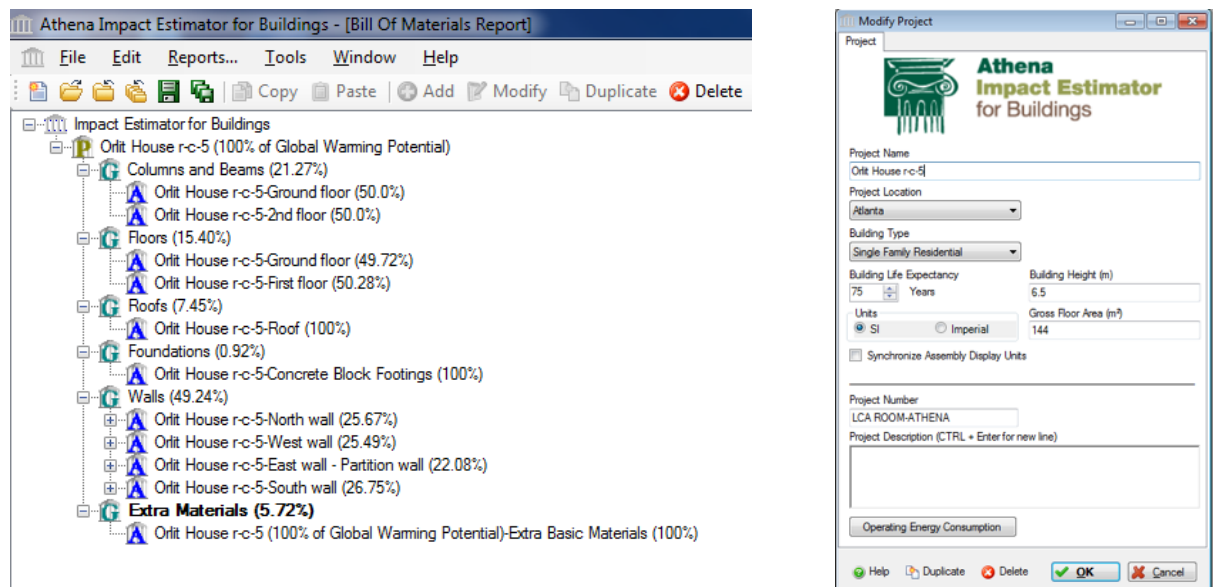
Figure 4.10: screenshot of Athena Impact Estimator when performing the practical test.

The program needs the annual operating energy usage if wanted to be taken into account for the LCA, adding this to the embodied, construction process and end-of-life energy.

Assessment Criteria:

The criteria in Athena are the following according with the TRACI v2.1 tool:

Table 4.11: Athena Impact Estimator criteria

Impact criteria	Indicator
Energy or resource	Embodied primary energy use
	Global warming potential
	Solid waste emissions
Environmental Impact	Pollutants to air
	Pollutants to water
	Natural resource use

Scale of assessment:

Building Materials and building´s life cycle including materials manufacturing, related transport, construction, maintenance, demolition and landfilling disposal.

Scoring/weighting System:

After specifying a design by selecting from typical assemblies or by entering specific quantities of individual products, Athena breaks down the selected assemblies into their respective products for the purpose of applying the LCI databases. Then the results are shown with the absolute inventory of materials with the summary impact measures mentioned above as a graphical or tabular format.

Present status:

Athena Impact Estimator for Buildings 4.5. Shortly release of v5.0.
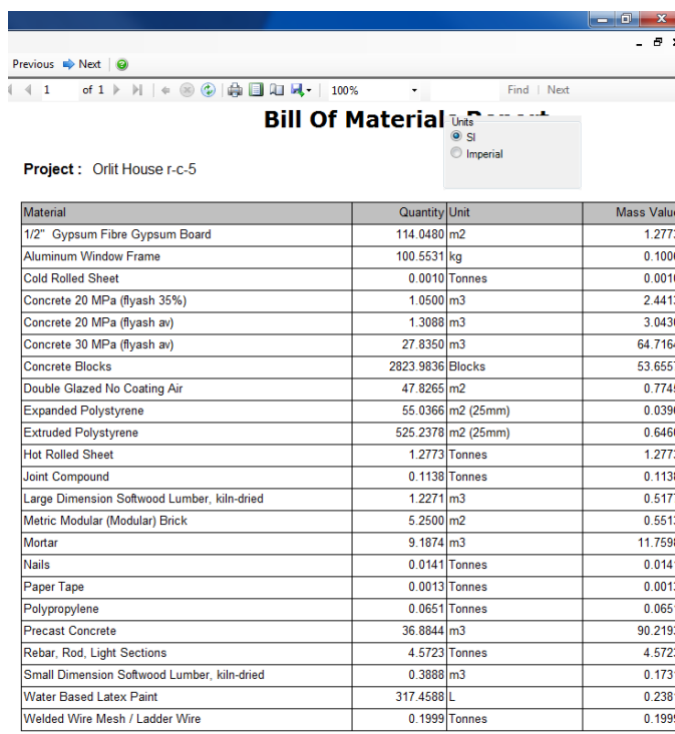
Key Factors:

With this software is possible to compare at the same time a maximum of 5 different projects which is very useful when modifying small things in order to see the overall improvement.

It is a normal size software because it does not calculate operational stage. Therefore it is need all the operation information from an external source, p.e. other software such as Design Builder or Calener. The database of construction materials or construction assembly options is not very extensive but good enough for the most typical social housing buildings with a concrete or steel structure.

The program generates a bars graph with the selected criteria evaluated. If more than one project is been evaluated then it shows the comparison between them quite clearly and easy to understand.

Instead of running the whole building, Athena institute has another tool: Ecocalculator which calculates the same six factors for elements individually in order to get a quick figure about how the project is going to perform globally.

Bill Of Material Units: ● SI ○ Imperial

Project : Orlit House r-c-5

Material	Quantity	Unit	Mass Value
1/2" Gypsum Fibre Gypsum Board	114.0480	m2	1.2773
Aluminum Window Frame	100.5531	kg	0.1006
Cold Rolled Sheet	0.0010	Tonnes	0.0010
Concrete 20 MPa (flyash 35%)	1.0500	m3	2.4413
Concrete 20 MPa (flyash av)	1.3088	m3	3.0430
Concrete 30 MPa (flyash av)	27.8350	m3	64.7164
Concrete Blocks	2823.9836	Blocks	53.6557
Double Glazed No Coating Air	47.8265	m2	0.7745
Expanded Polystyrene	55.0366	m2 (25mm)	0.0396
Extruded Polystyrene	525.2378	m2 (25mm)	0.6460
Hot Rolled Sheet	1.2773	Tonnes	1.2773
Joint Compound	0.1138	Tonnes	0.1138
Large Dimension Softwood Lumber, kiln-dried	1.2271	m3	0.5177
Metric Modular (Modular) Brick	5.2500	m2	0.5513
Mortar	9.1874	m3	11.7598
Nails	0.0141	Tonnes	0.0141
Paper Tape	0.0013	Tonnes	0.0013
Polypropylene	0.0651	Tonnes	0.0651
Precast Concrete	36.8844	m3	90.2193
Rebar, Rod, Light Sections	4.5723	Tonnes	4.5723
Small Dimension Softwood Lumber, kiln-dried	0.3888	m3	0.1731
Water Based Latex Paint	317.4588	L	0.2381
Welded Wire Mesh / Ladder Wire	0.1999	Tonnes	0.1999

Figure 4.11: screenshot of Athena Impact Estimator when performing the practical test. Bill of Quantities inputed.

4.3.4. Rating schemes

Environmental schemes, as indicated, are scoring systems. Since each scheme usually have their own method for each building typology, in this project only Eco-Homes has been deeply analysed since it is the only one dedicated exclusively to domestic buildings.

4.3.4.1.   Eco-Homes

Was developed by the UK in 1990 and is the building environmental assessment method with the longest track record. It covers a range of building types: offices, homes, industrial units and schools.

The LCA evaluation scheme is not publicly available for purchase and must be acquired through a licensed assessor. The licensed assessor organization determines the BREEAM rating based on quantifiable sustainable design achievements.

Data requirement: the required data is in two forms:

Quantitative: energy and water consumption, materials data, environmental profiling system based on LCA data (used to determine the credits attributed for materials)

Qualitative: the use of high frequency ballasts in fluorescent lighting, (a health and comfort factor) or whether efforts have been made to plant new trees (a site ecology factor).

Scale of assessment:

EcoHomes covers all standard housing developments in England, Scotland, Wales and Northern Ireland:

• private and social housing schemes

• flats/apartments and houses

• new build and major refurbishment.

For other types of housing – most sheltered homes, nursing homes, student accommodation etc, a bespoke EcoHomes assessment will have to be carried out.

Assessment Criteria: The criteria that EcoHomes assess are the following:

Table 4.12: EcoHomes assessment Criteria

Criteria		Description	Max Credits	Weighting (%)
01-	**Energy use**	Operational energy and CO_2 issues	24	22
02-	**Transport**	Transport related CO_2 and location related factors	8	8
03-	**Pollution**	Air and water pollution	11	10
04-	**Materials**	Environmental implication of building materials	31	14
05-	**Water**	Consumption and water efficiency	6	10
06-	**Land use and Ecology**	Greenfield and brownfield sites	9	12
07-	**Health and well being**	Indoor and external issues affecting health and well-being	8	14
08-	**Management**	Overall policy, commissioning and procedural issues	10	10

Scoring/weighting System:

For each of the criteria set out, the building is assessed against performance criteria set by BRE and awarded credits based on the level of performance against each criterion. The percentage of credits achieved under each category is then calculated and environmental weightings are applied to produce an overall score for the building. The overall score then translated into a BREEAM rating of "Pass", "Good", "Very good", or "Excellent".

Pass   36%

Good   48%

Very Good   58%

Excellent   70%

Present status:

The present version is Ecohomes 2006 for Scotland or projects registered prior to 8th of April 2012 and submitted before the expiry date.

Due to the introduction of the Code in April 2007, the EcoHomes scheme for 'new build' expired on the 8th of April 2012 in England, Wales and Northern Ireland. The above does not apply to EcoHomes 2006 New Build assessments in Scotland. Therefore, in April 2007 the Government's scheme, the Code for Sustainable Homes replaced EcoHomes for the assessment of 'new' housing in England, Wales and Northern Ireland.

This Code for Sustainable Homes was withdrawn on 2015, using their main aspects to consolidate Buidling regulations.

Key Factors:

The weighting system for the final score is predetermined through the national consultative process and so users cannot apply their own individual weighting priorities.

When evaluating the energy usage and CO_2 emissions (Ene 1 and 2), the evaluation is carried out by external schemes such as "SAP"

When evaluating goods (Ene 4) it uses the EU Energy Efficiency Labelling Scheme, from A to F.

For materials evaluation Ecohomes credits are achieved by obtaining an 'A' rating from the Green Guide for Housing Specification, for 80% by area of the element, for each of the main construction elements.

It takes into account social factor such as common access to public transport, comfort at home, possible disruption and some passive design factor for the better being of the users. Also it rate the possibility of the user for recycling the household waste. At the opposite, it does not take into account directly the economic factors.

Regarding the full Life Cycle Assessment it does not evaluate the end-of-life of the building or any of the processes involved in that.

4.4.   Scoring system created from the practical analysis

For the study, the methodology created has been with an evaluation scheme, separating "inputs and "outputs" of the programs analysed across different sections for all the tools, considered the most important aspects when assessing the LCA of domestic buildings [97].

Although the practical test's conclusions were discussed above, a scoring system has been developed in order to be able to rate all environmental tools analysed. So that, all three main stages of the building Life Cycle through descriptive, environmental, economic and social factors, including a user-friendly section of the programs, have been included.

4.4.1. Scoring system description

Programs have been fully analysed and rated with points where more points means better score with a total up to 190 points (90 for inputs and 100 for the outputs). There are six principal sections divided into sub-sections. Input and Output data has been evaluated across all sections. Every sub-section involves evaluative questions in order to score the points with a maximum of 5 points per sub-section. The section score consists in the sum of the comprehensive sub-section's points.

In addition, an overall score has been generated based for three extra Indicators: user-friendly, social and economic aspects that each program takes into account. Depending on how friendly and easy to use, intuitive visualization and management of the program, the economic cost data evaluation, and the social factors that the software evaluate within the LCA.

With this scheme, each program was evaluated globally and by sections so that it is possible to give a numeric value to each part of each program. Therefore, it is possible to establish among those evaluated which is the most comprehensive analysis for a lifecycle assessment for buildings and to highlights each section.

4.4.2. Sections considered

The sections and points are summarised on the following table:

Table 4.13: practical evaluation scoring system sections

SECTION	SUB-SECTION	Max Score		Other Factors		
Stage	Concept	Subt.	Total	Soc	Econ	User-f
Project and Climate date	Location	10				
	Goal and Scope	10	30	-	-	-
	Climate info	10				
Building and Geometry	Building Typology	5				
	Geometry	10	35	2	-	8
	Environment	10				
	Modelling	10				
Manufacturing Stages	Materials	10				
	Construction Elements	5	30	3	2	3
	Construction systems	10				
	Construction Waste	5				
Operational Stages	Activity	10				
	Appliances	5				
	HVAC	5	40	5	4	4
	Maintenance	10				
	Carbon Technologies	10				
End-of-Life Stages	Demolition	10				
	Recycling	10	40	1	1	1
	Energy recovery	10				
	Landfill Disposal	10				
Environmental Outcome	Impact Assessment Method	5				
	Life Cycle Inventory	5	20	1	3	4
	Life Cycle Inventory Analysis	5				
	Database	5				
Total maximum score (points):			**195**	**12**	**10**	**20**

A complete description of the sections evaluated, indicating inputs and outputs parameters involved are explain through this section.

4.4.2.1. Project and Climate

In this section it has been evaluated the method that the software has to take into consideration the project basic information and the climate conditions for its environment.

Regarding the outcomes, it has been evaluated the data that the program generates itself, regarding each section from the data entered. For this evaluation it has been taken into account the accuracy of the output, clarity and easy understanding of them and the different formats in which the program can provide those results to the evaluator/user.

Table 4.14: Project & Climate sections & points from scoring system created.

	SUB-SECTION	INPUTS		OUTPUTS	
Project and Climate	Location	How the location is entered. Existing database or other options	5	How the location is represented and explained on the final document.	5
	Goal and Scope	How is entered the Goal and Scope of the LCA. A form to fill in or documents.	5	How the Goal and Scope of the LCA is indicated and used within the evaluation	5
	Climate info	Information that the program has already about the climate data for that location or, if not, what climate file or data is needed.	5	How the program represents the climate data; graphically, table...for a better explanation according to the location and Goals and Scope.	5
30	Max Sub-total	Max Score Sub-total Inputs	15	Max Score Sub-total Outputs	15

4.4.2.2. Building and Geometry

When assessing the LCA of a building, the geometry needs to be described and represented as detailed as possible in order to make the virtual model the most realistic and close to the built model. All parts of the building need to be described within the LCA software and also de possibility to easily modify the components without a complete remake of model which would be a waste of time and resources.

When assessing at design stage, there are usually two parts: the first one when a basic model is evaluated just to advance its suitability in reality and if it is correct a more detailed model is done for a complete pre-build assessment. When assessing exists building the virtual model is the detailed one directly.

This section has assessed the program's ability to generate a visual feature and building information. Was taken into account how the program is able to interpret the inputs introduced with respect to geometry, immediate environment and building model and represent them. It has also been taken into account the program capability to generate a summary with this information for the better knowledge of the final user.

Table 4.15: Building & Geometry sections & points from scoring system created

	SUB-SECTION	INPUTS		OUTPUTS	
Building and Geometry	Typology	How the selection building typology is offered by the program, its life span and occupancy.	5	How the building typology, life span and occupancy selected affects the rest of components available for the LCA.	-
	Environment	How is possible to indicate the close environment of the project. Selection list or graphically.	5	How the selection of the close environment affects the calculations and assessment.	5
	Geometry	How the geometry is introduced into the program. The dimensions and orientation.	5	Interpretation of the geometry dimensions and orientation for the program.	5
	Modelling	How is created the virtual model in the program.	5	The result of the virtual model created	5
35	Max Sub-total	Max Score Sub-total Inputs	20	Max Score Sub-total Outputs	15

4.4.2.3.   Manufacturing stages

The issue within the input section is to evaluate how the data related to the manufacturing stage in the LCAoB is introduced. This refers to a wide range of matters such as materials used in construction of buildings, how to describe in the program the elements and building systems that are to be executed in its construction and the versatility of the program when managing and modifying these databases that facilitate the introduction of these parameters.

This building phase is usually addressed within the software with a database that can be characteristic of an external that could be inserted. Many of them use the "Excel" program for these databases. Therefore sometimes it is easier and quicker to modify them or create private databases.

For the outputs was assessed whether the program calculates the environmental data relating to the materials used, the construction process of the building and construction elements separately. It evaluates how the program presents these data for a better understanding and comparison. It has also been taken into account if the program calculates the amount of construction waste and possible functions with them.

Table 4.16: Manufacturing sections & points from scoring system created

SUB-SECTION		INPUTS		OUTPUTS	
Manufacturing Stage	Construction Materials	Completeness of the material database. Customising options. Transport and economic data.	5	How the calculation of energy and gas emissions per material is presented. Comparison.	5
	Construction Elements	Database that is possible to generate.	5	-	0
	Construction Systems	Construction components options. Social disruption on construction process. Time and transport	5	Methodology of calculation environmental, social and economic data during construction process.	5
	Construction Waste	-	0	Construction waste management. Options and results.	5
30	Max Sub-total	Max Score Sub-total Inputs	15	Max Score Sub-total Outputs	15

4.4.2.4.   Operational stages

The Input section evaluates how LCA programs address the use phase of the building and as such phase data can be entered when creating the virtual model. For this the programs must have huge databases (or access to them externally) regarding several purposes: the activity loads that will be held in the building during its life span, which ideally will be linked to on the type of building it and type of occupancy, all electrical and non-electrical appliances that might be used during this stage, HVAC facilities and systems as well as maintenance and renovation processes of the building studied. It is valued in each section independently if the program offers the possibility of introducing economic data of the energy consumed and materials.

Often this section is evaluated separately with more specialized programs in this phase of occupation of the building. These are usually called "Energy Performance Software", which specifically evaluate environmental data relating only to the use stage of the building studied. They tend to be better developed and to have the necessary databases for energy and environmental in-depth study of the operating stage of the building leaving the other stages away. There are cases in which some LCA programs do not perform the energy analysis of the building but use the data resulting from these "energy programs" as inputs to this section. This usually could lead to lighter and more specialized software in the remaining phases.

Regarding the outputs, the operational phase of a building is marked by its intrinsic activity. The building materials and their environmental data are taken into account only if reform or renewal but are not predominant in this section. Thus the data obtained in this section are primarily energy consumption and CO_2 emissions produced by the normal use of a home and its appliances.

Table 4.17: operational sections & points from scoring system created

	SUB-SECTION	INPUTS		OUTPUTS	
Operating Stage	Activity	The insoles of scheduling options for use that the program has. Activity levels and options of customise.	5	Results from thermal comfort calculations. Comparison against other patterns.	5
	Energy Appliances	Detail on energy appliances and load pattern. Customised options.	5	-	-
	HVAC facilities	Database according to climate and location.	5	-	-
	Maintenance	Maintenance options: frequency and depth. Social and economic evaluation.	5	Results from calculation. Comparison against embodied energy and whole Life Cycle. Book of maintenance.	5
	Carbon Technologies	Renewal energy database options. Passive design recommendations.	5	Type of results and comparison against UK carbon targets	5
40	Max Sub-total	Max Score Sub-total Inputs	25	Max Score Sub-total Outputs	15

4.4.2.5.   End-of-life stages

This section deals with the final stage of the buildings, its end of life. It is assumed here that the building is outdated or with no suitable conditions for the primary use and must be renewed in depth, changing its use or demolition. The LCA program should allow these options within the inputs when introducing the existing techniques at the time of analysis, offering different possibilities for it most sustainable solution.

Within the outputs has been evaluated the data that the program generates regarding the end of life of the building. Here all possible procedures for the dismantling of the materials of a building come into play, but the assessment only has taken into account those relating to the demolition, recycling (with reuse in different industries), incineration and landfill accumulation.

Table 4.18: End-of-life sections & points from scoring system created

SUB-SECTION		INPUTS		OUTPUTS	
End-of-Life Stage	Recycling	Recycling options. Customise the quantity of material. Transport.	5	Results and environmental loads allocation. Comparison against other options. Easy to understand graphs.	5
	Incineration	Transport to incineration site. Treatment options: ash, gas, or heat recovery	5	Calculation of environmental loads due to incineration. Comparison.	5
	Disposal	Transport to disposal site. Amount of material. Recommendations.	5	Calculation of potential recycling wasted. Recommendations.	5
	Demolition	-	0	Calculation of the demolition. Structure options.	5
35	Max Sub-total	Max Score Sub-total Inputs	15	Max Score Sub-total Outputs	20

4.4.2.6.   Environmental Outcome

In this section has been evaluated the environmental outcome of the program. This is the impact method they use, the life characterisation they do of the life cycle inventory, the normalisation and the weighting units (if they give a final score).

It is been scored how the programs are able to use and modify the Impact Method used. It has also been valued how easy to interpretation of results and a better understanding of the building impact, its components and materials used within the whole Life cycle. This section has been only analysed within the Outputs:

Table 4.19: Environmental outputs sections and points from scoring system created

SUB-SECTION		INPUTS		OUTPUTS	
Environmental Outcome	Impact Assessment Method	-	-	Different options of calculation. Customising the methodology. Criteria and indicators.	5
	Life Cycle inventory (LCI)	-	-	How the program shows the results and how easy to get specific data.	5
	LCI Assessment	-	-	How the program gives the results. Comparison across construction components.	5
	Life Cycle Cost	-	-	Footprint value. Carbon and energy strategies.	5
20	Max Sub-total	-	-	Max Score Sub-total Outputs	20

4.4.3. Evaluations results

The summery tables of results from this part of research are shown below:

Table 4.20: Software scoring results. Inputs

	SOFTWARE TOOL	PROJECT AND CLIMATE (Max. 15)	BUILDING AND GEOMETRY (Max. 20)	MANUFACTURING STAGE (Max. 15)	OPERATING STAGE (Max. 25)	END OF LIFE (Max. 15)	TOTAL (Max. 90)
EPoB	Calener VYP	8	18	13	18	0	57
	Design Builder	14	16	13	19	0	62
	IES	14	18	11	15	0	58
LCA	TEAM 5.1	5	4	10,5	8,5	8	36
	SimaPro 8	8	9	8	7,5	12	44,5
	GaBi	7	8	8	5	10	38
	Athena Impact Estimator	3	11	15	3	9	41
	OneClick LCA	9	5	15	6	11	46
Score scheme	EcoHomes	9	4	2	13	3	31

Table 4.21: Software scoring results: outputs

	SOFTWARE TOOL	PROJECT AND CLIMATE (Max. 15)	BUILDING AND GEOMETRY (Max. 20)	MANUFACTURING STAGE (Max. 15)	OPERATING STAGE (Max. 25)	END OF LIFE (Max. 15)	ENVIRONMENTAL DATA Max 20	TOTAL Max 100
EPoB	Calener VYP	7,5	10	0	7	0	0	24,5
	Design Builder	7,5	13	0	8	0	0	28,5
	IES	7,5	11	0	7	0	0	25,5
LCA	TEAM 5.1	2,5	2	3	2,5	3,5	9,5	23
	SimaPro 8	5	9	8,5	4,5	8	16,5	51,5
	GaBi	0	5	5	3,5	8	9,5	31
	Athena Impact Estimator	0	5	8,5	6	7,5	12,5	39,5
	OneClick LCA	2	5	10	5,5	10	17	49,5
Score scheme	EcoHomes	5	0	2,5	3	2	0	12,5

Table 4.22: Software total score by sections

	SOFTWARE TOOL	PROJECT AND CLIMATE Max 30	BUILDING AND GEOMETRY Max 35	MANUFACTURING STAGE Max 30	OPERATING STAGE Max 40	END OF LIFE Max 30	ENVIRONMENTAL DATA Max 20	TOTAL Max 190
EPoB	Calener VYP	15,5	28	13	25	0	0	81,5
	Design Builder	21,5	29	13	27	0	0	90,5
	IES	21,5	29	11	22	0	0	83,5
LCA	TEAM 5.1	7,5	6	13,5	11	11,5	45,5	95
	SimaPro 8	13	18	16,5	12	20	61	140,5
	GaBi	7	13	13	8,5	18	47,5	107
	Athena Impact Estimator	3	16	23,5	9	16,5	53,5	121,5
	OneClick LCA	11	10	25	11,5	21	63	141,5
Score scheme	EcoHomes	14	4	4,5	16	5	31	74,5

Table 4.23: Software total score by Factors

	SOFTWARE TOOL	Social INPUTS Max 2	Social OUTPUTS Max 9	Economic INPUTS Max 1	Economic OUTPUTS Max 4	User-friendly INPUTS Max 8	User-friendly OUTPUTS Max 13	TOTAL Max 37
EPoB	Calener VYP	0	0	0	0	6	4	10
	Design Builder	0	1	0	0	5	5	11
	IES	0	1	0	0	6	2	9
LCA	TEAM 5.1	0	0	0	0	1	3	4
	SimaPro 8	0	0	1	1	3	8	13
	GaBi	0	0	0	0	2	3	5
	Athena Impact Estimator	0	0	1	1	3	9	14
	OneClick LCA	0	0	1	2	3	8	14
Score scheme	EcoHomes	2	6	0	0	3	0	11

From the results obtained, it is possible to see that Design Builder gets the best score either in "INPUTS" and "OUTOUTS from the energy performance programs, in which IES is included. Having also the best general score for inputs across all the programs. It is remarkable the options that Design Builder lets within the operational stage of the inputs and the building and geometry at the outputs.

On the other hand the EPoB programs get the lowest average score if outputs are evaluated. That is due to the nature of the programs which is specific for operational stage rather than the whole life cycle.

For LCA the highest score in both main sections, inputs and outputs is OneClick LCA. This program was evaluated in its full version so this could be possible the difference with other only assessed with the demo version. Anyway it is clear that OneClick LCA is a very complete LCA program that needs a very high level of knowledge about it.

The second-best scored tool within the LCA is SimaPro which also gets the best score due to its very friendly and easy to use interface and because it could consider economic factors very easily.

4.5.   Conclusions

The main conclusion is that it becomes really difficult to compare the LCA from different programs. There is no transparency of impact methodology, and they all use different criteria, weighting units and outputs.

The databases are kept inaccessible, so it becomes a very difficult task to know the environmental impact factor for each material and construction element. Therefore, it becomes very difficult to use the tools as decision making tools at the design stage.

There is a general lack of end-of-life deep assessment. In most of the cases is just a percentage of the material which is taken into account for the recycling and landfilling options. The LCA tool should give the evaluator the opportunity to choose the amount of material designated to each possible recycling method. This is recycling, incineration or disposal.

Factors usually avoided on LCA tools, or on a very first steps of including them in the global process are economic and social factors.

The economic factors, in general, are not taken into account within the life cycle assessment. It has a difficult methodology, even if some studies tried already to do so because of the market-values and different options for each particular case.

Regarding the social aspect of the Life Cycle of buildings, EU and the UK look for this integration through the standards of sustainability and new carbon strategies. Although BREEAM, through EcoHomes has into account some factors that fit into these matters (i.e. to have a nice work environment at home, access to facilities and public transport at the surrounding area, bike storage), there is a lack of assessment methodology to be applied in order to get a sound analysis of the social problems when addressing the built environment.

The tools today are mostly used to evaluate an existing project and leave the current user without reaction capacity. Programs should be easy to use and applicable in the design stage in order to anticipate and get a full evaluation of the building before construction and thus achieve the best possible solution for further optimization of material resources, energy used, environmental values (gases emissions) and total economic cost, also adding social factors, urban issues, recyclability assessments and innovation values. In addition we also need to look for tools for the renovation of existing buildings. In 2016 all the buildings of new construction should had been zero emissions and the same applied to the vast existing stock from 2050 so most of the houses built

today must be modified to achieve these goals. For this we will need to develop a tool to assess the best possible solution for the renovation.

Regarding the impact assessment, results have shown that the different steps of the process would need to be addressed with a simpler method for a general better understanding of the Life Cycle Analysis.

Although the Life Cycle Inventory results could provide the most detail, would not be easy the interpretation of these long lists of substances. ISO 14040 specifies a number of procedures for an impact assessment that can be used to better understand the inventory results. TO CHP.3?

The characterisation step is an obligatory step in impact assessment by ISO 14040. All effects are scaled to 100% because each category can have a different unit. Each column represents the impacts arising from different subassemblies in the production stage. Usually, characterisation is shown with a bars graph. It is impossible to compare anything between other elements because they have different units. Thus, a normalisation (analysis) is needed. It is still not easy to see which parts of the assembly have the highest overall environmental impact. Each bar in the graph could represent 100% of a very large impact, or equally 100% of a small one. TO CHP.3?

The analysis of the Life Cycle inventory is called Normalisation. Normalisation is an optional step in impact assessment and can be described as a kind of benchmarking. In this process, each element is normalised to the environmental effects that are caused by one average European person in one year. Thus, impacts are now compared on a scale of inhabitant equivalents. This gives much more insight in the size of the various environmental effects.

Normalisation only reveals which effects are large or small in relative terms. It says nothing about the relative importance of these effects. Thus, if a final scored is wanted, that normalisation results need to be weighted. In other words, they need to be classified and multiplied regarding its importance in terms of sustainability.

When a weighting factor has been applied to each element of the normalisation results, the results have a certain level of seriousness. Once this is done, it would be possible to give a final score to the building and each program use different and private weighting units. Therefore, when a final scored is given it not possible to know how subjectively that grade has been awarded.

The core of the Life cycle Assessment is the Impact method that each program uses. It depends on what they have into account when analysing the environmental load of a product, in this case the product is a complete building. Weighting is a subjective step. According to ISO 14044 [69], weighting may not be used in case of public comparisons between products.

Gaps in research

Environmental design parameters need to be considered as early as possible in the assessment process. If they are not dealt with at the outset and during the appraisal stage of a project, later alterations to the brief will cost money, cause time delays and promote friction within the design team [95]. This should be taken into account in order to minimise environmental damage, potentially maximise the specification of low embodied energy materials and reduce remedial costs. Currently environmental performance tools tend to be applied at a stage when it is too late to consider any changes [96]. In addition, the majority don't include end-of-life, financial and social aspects in their evaluation framework due to the already complexity of the assessment [76].

5

CHAPTER 5: NEW SIMPLIFIED OPTIMIZATION LCA TOOL

5.1.   Goal and Scope

The aim of this methodology is to generate a simplified calculation scheme in order to estimate the Life Cycle Assessment of new and existing domestic buildings. This scheme and its environmental data processing calculations will be performed with a user-friendly tool using Matlab commercial software package [98].

The intention of this research is to have a quick and easy-to-use assessment tool at an early design stage of the building, when the decisions could be more cost-effective for the housing project, as stated in Section 1.1. Introduction.

The global scope of this methodology is the domestic sector and its most used typologies within the UK such as the 4-in-block building type. Although the main focus of this research is to improve the social housing environment and its communities, other housing typologies, such as detached or multi-storey housing, could be used for the validation process of the proposed calculation tool.

The specific scope is the improvement on building fabric decision-making selection. The calculation methodology focuses on the embodied energy and carbon of the main materials used within the complete building and its life cycle calculated from those manufacturing impacts. It goes through manufacturing stages and transport, construction process and operational phase until the end-of-life of the building and demolition and the disassembly takes place.

The purpose of the LCA of buildings is to quantify the impacts (energy and carbon flows) of all materials and processes involved within the construction sector. This quantification model should be structured in a way with which a clear and direct response to LCA problems are achieve. To get this quantification this proposed tool divides the building model into the following parts:

- Building parts such as elements, materials and products involved.
- Related processes such as construction, transport of materials and end-of-life.
- Operational energy use.
- Optimization factors.

5.2.   Simplified optimization LCA methodology

This section aims to explain how the calculation tool, object of this PhD project, works and calculate all environmental impacts from domestic buildings within the typologies accepted.

5.2.1.   Optimization tool calculation steps

The method used for this assessment is in line with the European Standards about sustainability in construction works EN 15978 and ISO 14040 family [2, 99]. It is based on the following 5 steps according to the following framework:

- General Project Information
  - Building Project information
  - Building Measurements
- Physical description
  - Substructure
  - Superstructure
  - Interior Finishes
- Database match
- Environmental calculations
  - A-Manufacturing
  - B-Use
  - C-End-of-use
- Optimization
- Reporting the results
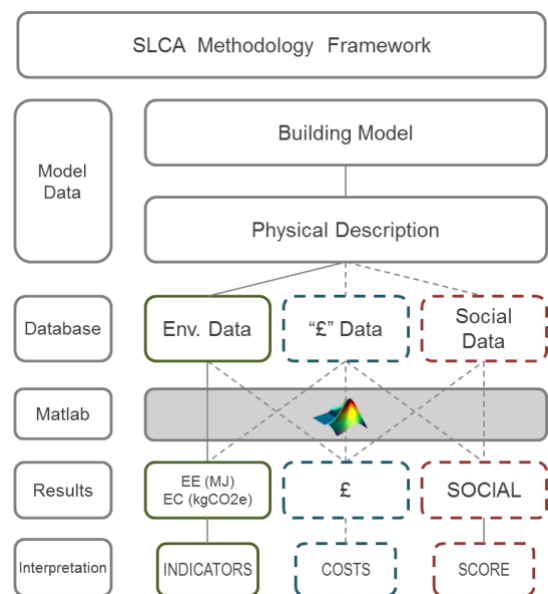
Figure 5.1: Simplified LCA method proposed

Only environmental data is involved in this method. This environmental data will be reported embodied carbon with equivalent mass of CO_2 emissions and embodied energy with MJ, related to construction materials and life cycle processes involved within the building assessed.

First step is to get general data about the building such as location, global measurements and set up the goal and scope of the LCA.

Then a detailed physical description and LCA scenarios is described in order to get all components of the building elements within the building life span.

This process is followed by matching the environmental data with all components and the calculations about all LCA stages described before: product, construction, replacement and end-of-life, using Matlab Software [98].

Then further calculations have been implemented for building impacts optimization of insulations materials depending on the location in which the building had been placed. Then results are displayed in both spread sheet files and graphically.

As stated on chapter 3, social or economic factors are not part of the scope of this research. Hence, they could be added to future work as extension of the current calculation tool.

5.2.2. Normative references

The simplified methodology proposed is in line with the calculation method prescribed on EN 15978:2011 and EN 15804+A1 [78, 99] for Environmental performance of buildings and products. This first standard considers the whole building as a product. Hence, the complete building would be considered as the functional unit of the assessment in this proposed methodology.

Although the method proposed has been developed having into account the ease of database substitution if needed in case future development could be audited by a third party and any specific format is needed, only comparisons between buildings would be made, nor between elements nor products themselves.

5.2.3. System boundaries.

This simple methodology takes into account all main LCA stages according to the environmental standards [78]. These include manufacturing of material and its transportation (to site and to landfilling site), construction and end-of-life environmental impacts due to building activity excluding the manpower operations.

For the simplified methodology proposed the LCA stages involved are the following:
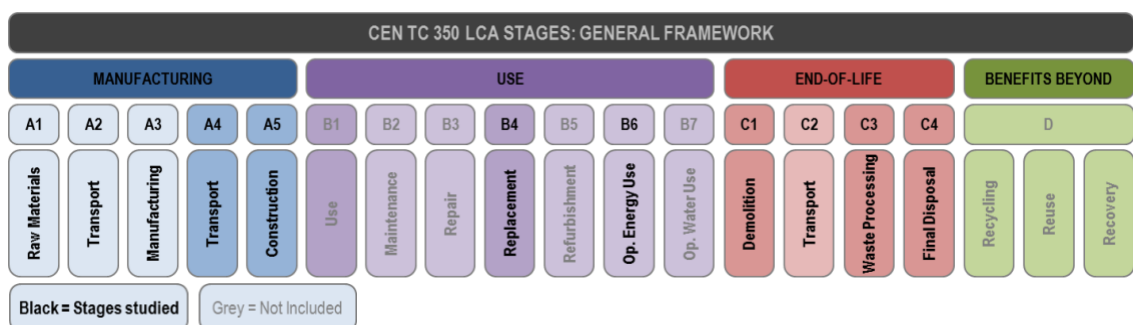
Figure 5.2: LCA stages included in the new simplified methodology

All sub-stages of the "Manufacturing" stage (LCA-A Stage) are included.

Within the "Use Stage" (Stage B) the methodology only will take into account the material's replacement (B4) for the RSP studied. Use sub-stage (B1) is not included due to the exclusion of refrigerant fluids or similar substances with emissions. Maintenance (B2), repairments (B3) and refurbishment (B5) sub-stages are not include having into account that maintenances duties for domestic buildings are all fairly similar and only new construction buildings would be assessed, hence, neither repair nor refurbishment could be considered. The same happens to operational water consumption (B7) within the operational sub-stages.

The operational energy use (B6) won't be calculated by the tool as it is known that energy modelling software tools are more advanced and detailed for that matter. However, the tool considers these impacts for the results calculations. If there is no more specific energy modelling data, the user could select "average" or "good-practice" energy demand benchmark in order to give a reference value for this LCA stage.

Regarding the "End-of-life stage" (stage C) all sub-stages are considered using assumptions explained during this chapter.

The last stage "Benefits beyond the End-of-life" (Stage D) is not part of the scope of this simplified methodology due to the big difficulties that would involve predicting what could happen with the re-using, recycling or energy gains from materials in a 60 to 100 years period. This could lead to uncertain assessments, and it only could be done having into consideration current industrial practices and technologies. These industry technologies for these processes can potentially evolve in such a way that makes any assumption be very unpredictable.

When performing a LCA assessment a lot of assumptions have to be taken. These assumptions are always according to the closest reality that can be modelled. All assumptions taken within this methodology are explained along this chapter. They are adopted to be close to reality due to the case studies considered. In any case, for specific cases or user, they can be easily adapted. This is also part of the user-friendly aspect of the tool.

5.3.   Operation of the tool

The proposed calculation tool has been designed using Matlab software. In fact, it is a composition of almost 70 files with the usual Matlab format ".m". These files are also called Matlab programs since each of them has a transcript code created within the "editor" window of the software. Within the transcript, not only code have been created, but also titles and comments for the user and myself to follow the specific aim of some sections and lines.

Hence, to run this tool, Matlab software 2020a or above is needed with a valid license. Full LCA tool transcript can be seen on Appendix D.

5.3.1.   General comments of the Matlab tool program files

Matlab is ready to open any program contained in the directory in which it is operating. that could be seen in blue within the picture below. Matlab files are also called, within this thesis, program files and they have an extension ".m" which is the usual coded file for this software.

When a file is opened, its written script is the code contained in each program file, is shown on the Editor window, coloured red on the picture below.

If the script contains any input command, as it is the case, the interaction between the Matlab tool and the user takes place within the "Command window" of the software, coloured in orange on the picture below.

Having an opened program file with a valid code, and a user to execute that program, lots of variables will be generated and they will be stored in the "workspace" window of the software. They can be saved to a ".mat" format file for future use. So the user can clear the workspace and work with other program projects assessments. Once the user wants to return to the previous project, it is only a matter of loading the ".mat" file and continue where it was left.

The LCA tool has been coded so that the variables and results are automatically saved both in the matlab ".mat" file and in excel file ".xls". The first type will let the user to load those variables in the future and continue the evaluation if left before a complete LCA was finish. The second type will let the user analyse the results on a much more common format.

Additionally, the code has been written to be performed with both windows and MacOS operating systems, as it can be seen on the comments shown at the Appendix D.
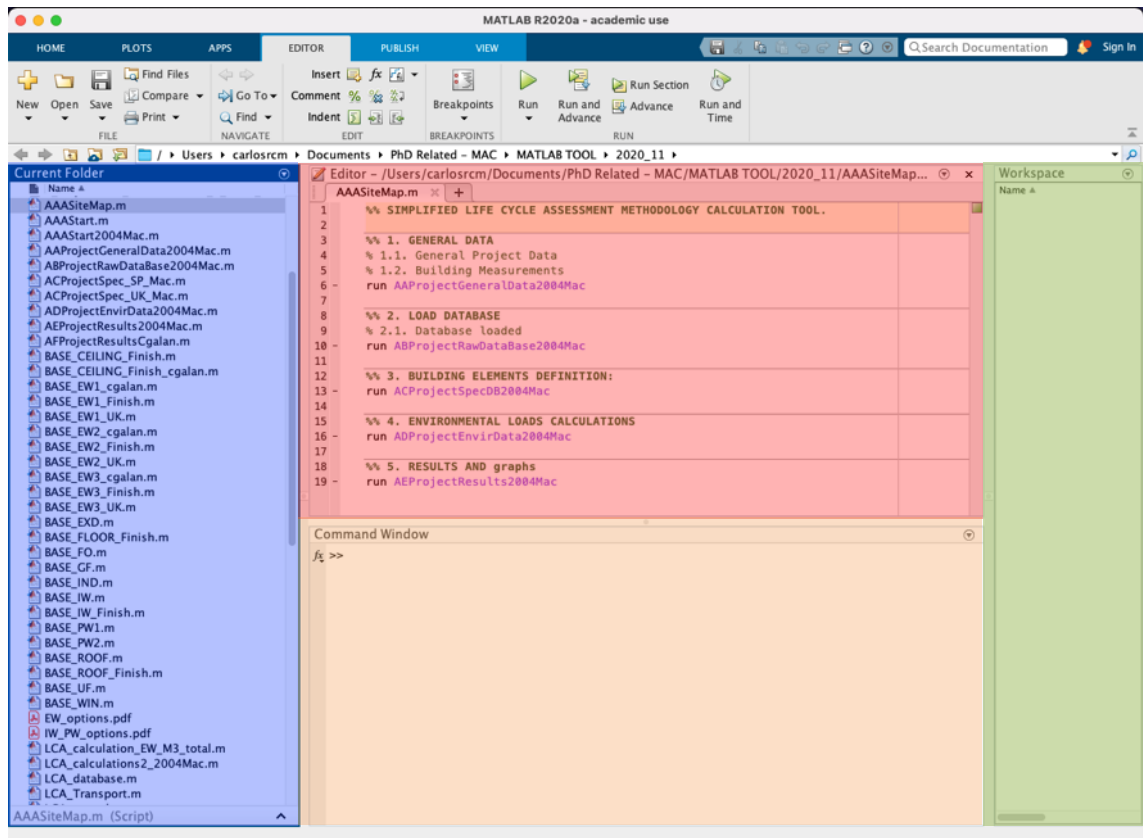
Figure 5.3: Matlab software screenshot. View of the different windows used.

Some program files relate to others and will "run" them automatically. They can also be executed independently, however, for that to happen the tool needs have loaded all previous variables in the "workspace" window. This is the case because the tool performs with a to following certain order of inputs and specification.

With that, if a complete LCA is performed in a row, the tool is able to calculate the environmental impacts of a complete building within 5 to 10 minutes.

5.3.2.   Tool interaction with the user

This section will explain how the tool interacts with the user, and how the user will input the data asked by the program to continue the LCA.

As indicated before, programs files have been designed to "execute" other program files, so the user only need to open and run the main ones. All parts and order of the program files will be explained in detail along the following subsection.

The way in which program files "ask" the user for any input is with the code "*Variable=input ('text shown on command window')*", to which the program will assign a variable that will be later used to generate results or as a part of other variables.

Once the user executes the program file, the "input call" pops out within the "command window" of the software, and the user will need to either input a valid character or chose between different options indicated, inputting the number or letter associated to that option.

Below it could be seen two examples of inputs. The first one is the general one, in which the user will need to input a complete word, in this case the name of the project evaluated. The second one, the type in which the user will need to input the number assigned to a specified option for the tool to use it for future variables or results.

This way, the user will be answering all questions that the tool will need to calculate the complete LCA. These questions are mainly general data of the project and selections from different options for the construction elements description of the building. So that, the user won't need to be an expert of the field to calculate the LCA, but he will need to know the main materials with which the building has been design.
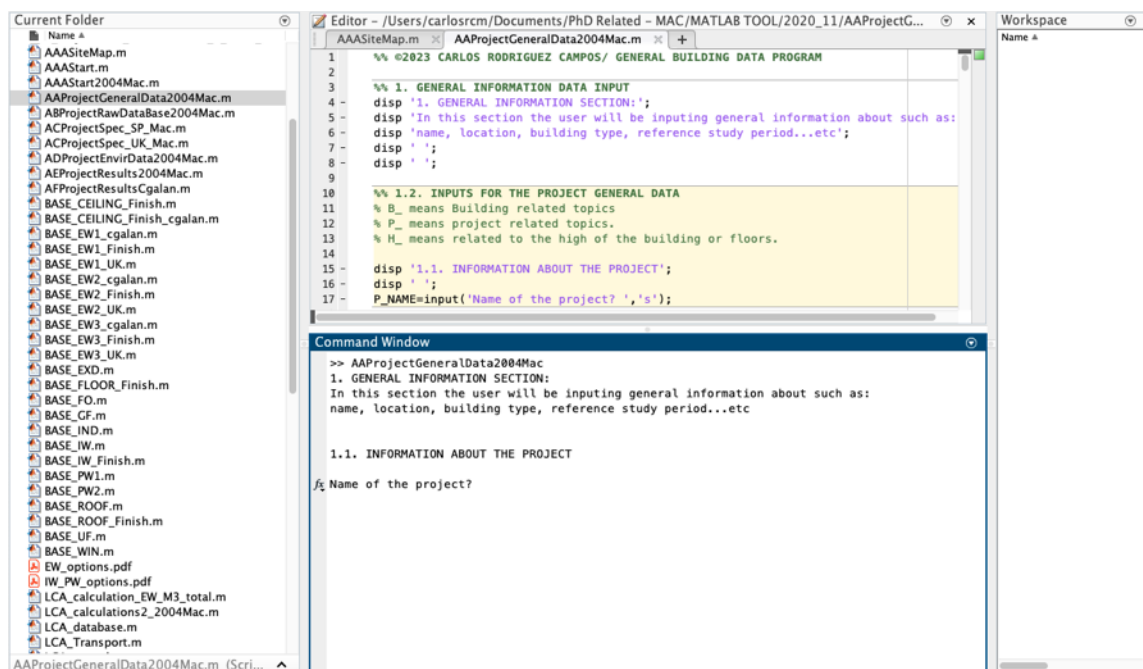
Figure 5.4: LCA tool screenshot. Example of input "Name of the project?"
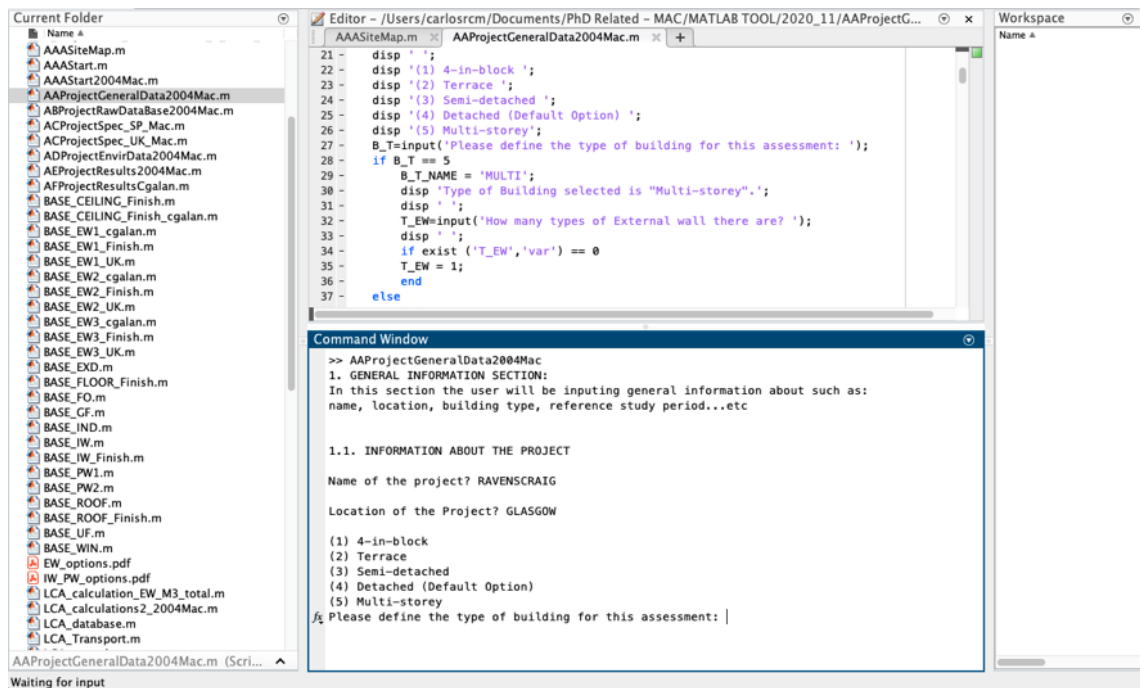
Figure 5.5. LCA Tool screenshot. Example of input with different numbered options for the user for type of building assessed.

5.3.3. Tool order of performance

As it has been mentioned before, the tool performs following certain order of program files and variables. Main program files are the following:

1. General data gathering – "AAProjectGeneralData2004Mac.m"
2. Loading the database – "ABProjectRawDataBase2004Mac.m"
3. Specific building elements definition – "ACProjectSpec_UK_Mac.m"
4. Tool calculation algorithms – "ADProjectEnvirData2004Mac.m"
5. Reporting numerical and graphical results – "AEProjectResults2004Mac.m"

With this program files, the tool will gather all the information needed for a complete assessment, although they will need the action included in other files. The complete list of the Matlab tool, in terms of program files, is available on Appendix D.

The content that is gathered and all the possible user options, within each of the main program files commented, will be explained along the following sections, including screenshots of the process that the user will need to perform for any evaluation.

5.4.   (1) General data gathering

The aim of this section is to explain how the proposed tool gathers the building information data needed for the LCA process. The information will be used for LCA reports and environmental impacts results.

5.4.1.   Functional Equivalent

The functional equivalent in this proposed simplified methodology, will be the complete building, with all its elements and materials involved, in line with EN 15978:2011 standard [99]. Thus, results and global environmental figures accomplished following this method could be compared with other complete buildings or by unit of area. External areas of the building site are excluded from this calculation tool.
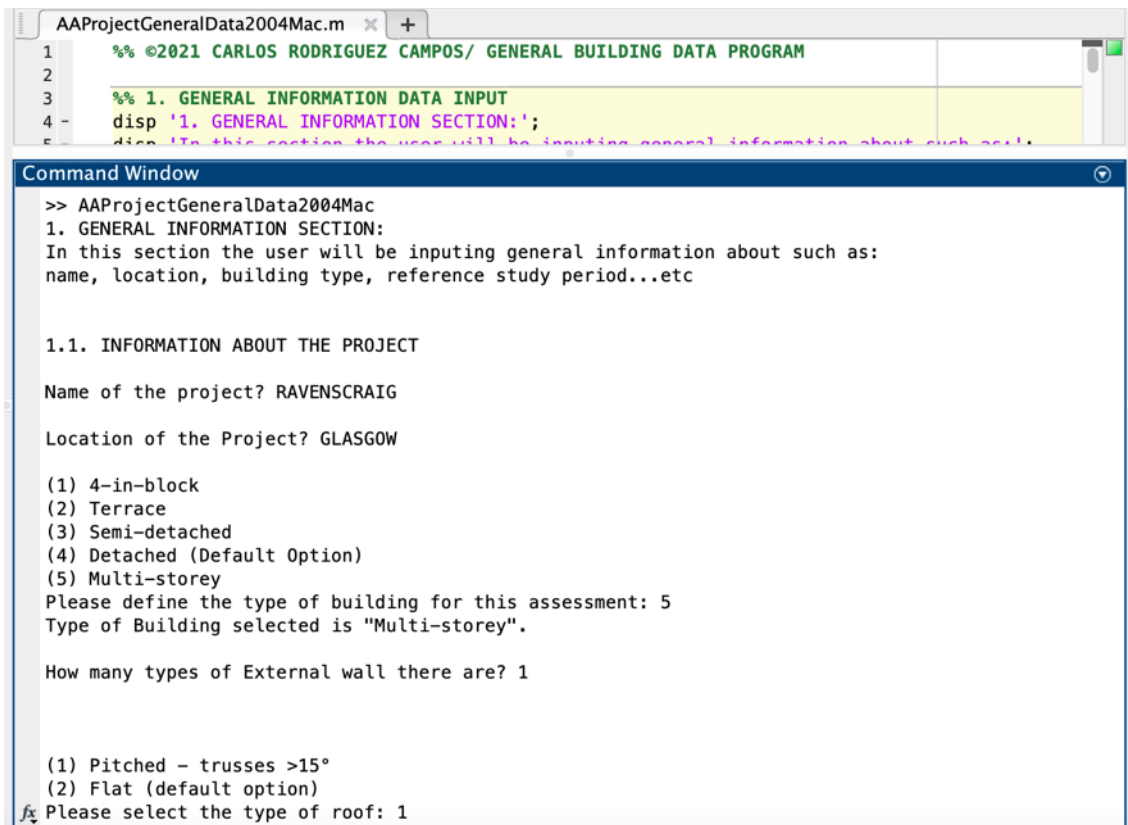
The information from this section, would be used for the final LCA Report and consist of the first approach to the building. The developed tool would be asking the user all this information with the Matlab interface. User would need to input then, manually or selecting the options prompted from the tool itself.

To get the general description of the building, the following data is considered, including typology, location, number of floors and RSP. The table resulting from this section would be saved automatically on a new spreadsheet ready to be gathered, as follows:

Table 5.1: General Information gathered by the tool

General Information	Data
Name of Project	*Name*
Location	*City*
Climate zone	*Zone*
Type of Building	*Typology*
Reference Study Period	*Years*
No. of external walls (except for detached)	*No*
Type of Roof	*Pitch/flat*

After having defined the typology of building, roof is selected between flat or pitched. If this last is selected, then inclination will be defined in degrees. This will be for net roof area calculation and possible future graphic representation.

Figure 5.6: screenshot of Matlab's "command window" when defining the general project information

Typologies accepted, for which the tool would give a selection option, are the most common domestic units, described as follows:

(A)

(B)

(C)

(D)

(E)

Figure 5.7: building typologies

From left high corner:

   (A) 4-in-block
   (B) Semi-detached houses
   (C) Terrace houses
   (D) Detached house
   (E) Multi-storey buildings

5.4.2.   Building measurements

This section refers to main building elements areas that lately will be matched with the construction elements specifications within the project, explain below on this chapter. These areas will be used for matching all environmental impact to exact measurements of building elements. Then, net areas of these are needed and could be obtained automatically from architectural drawings, 3D models, energy models or manually from cad drawings of each project.

For accordance with the functional equivalent described before, these measurement model also uses RICS specification rules of measurement [100].

This data could either be inputted manually into Matlab by the user, when asked for, or extracted from a prefilled template spreadsheet that the tool will automatically recognise and process the data. Once the Matlab tool has obtained these measurements, from either way, the variables will be loaded into the "workspace" of the program. Measurements needed by the tool are the following:

Table 5.2: Building Measurements

Building Element	Unit
Footprint Area	m^2
Floor Area (G.I.F.A.)	m^2
Upper Floor Area (net)	m^2
Roof Pitch inclination	° (Degrees)
Roof Area (net)	m^2
Gross External Wall Area	m^2
External Wall [(1)] net area	m^2
External Wall [(2)] net area (if any)	m^2
External Wall [(3)] net area (if any)	m^2
External Window (net area)	m^2
External Doors (area)	m^2
Gross Internal Wall area	m^2
Internal Wall area (net)	m^2
Party Wall area (net)	m^2
Internal Door area	m^2
Internal Door (count)	*Units*
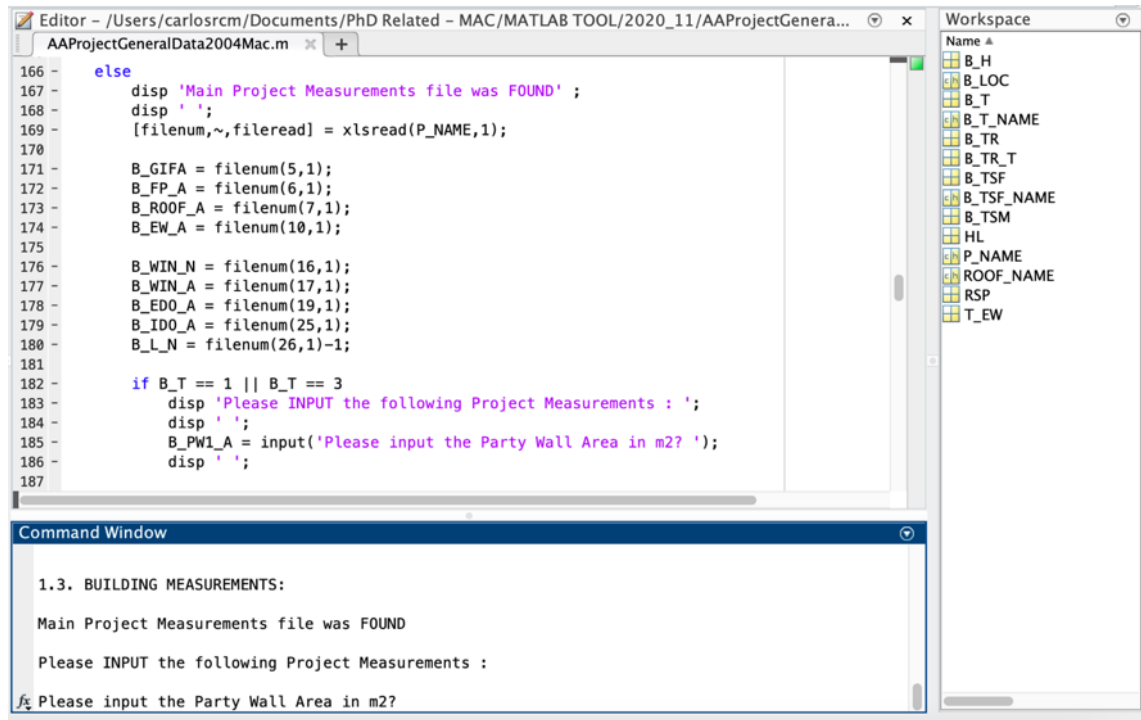
Figure 5.8: screenshot of Matlab tool when finding the predefined building measurements and asking for the "Party wall" area.

Once the building measurements are loaded the tool will ask for the reference study period and will ask the user to continue with the following main program file to load the complete database into the "workspace" of the software.

Before stepping to the next program file, the tool will save all general information and measurements into an excel spreadsheet called "1_ProjectGENdata.xlsx".

5.4.3. Reference Study Period (RSP)

As explained before, the Reference Study Period (RSP) is the length, in years, of the operational phase of building for which the assessment will be carried out.

Within this proposed methodology, reference study period could be selected by the user. The default option would be 60 years but any period of in 5-year intervals would work well.

This RSP be used in junction with the required service life (ReqSL) of materials in order to get the number of replacements for each material. The calculation tool prompts the questions as follow:
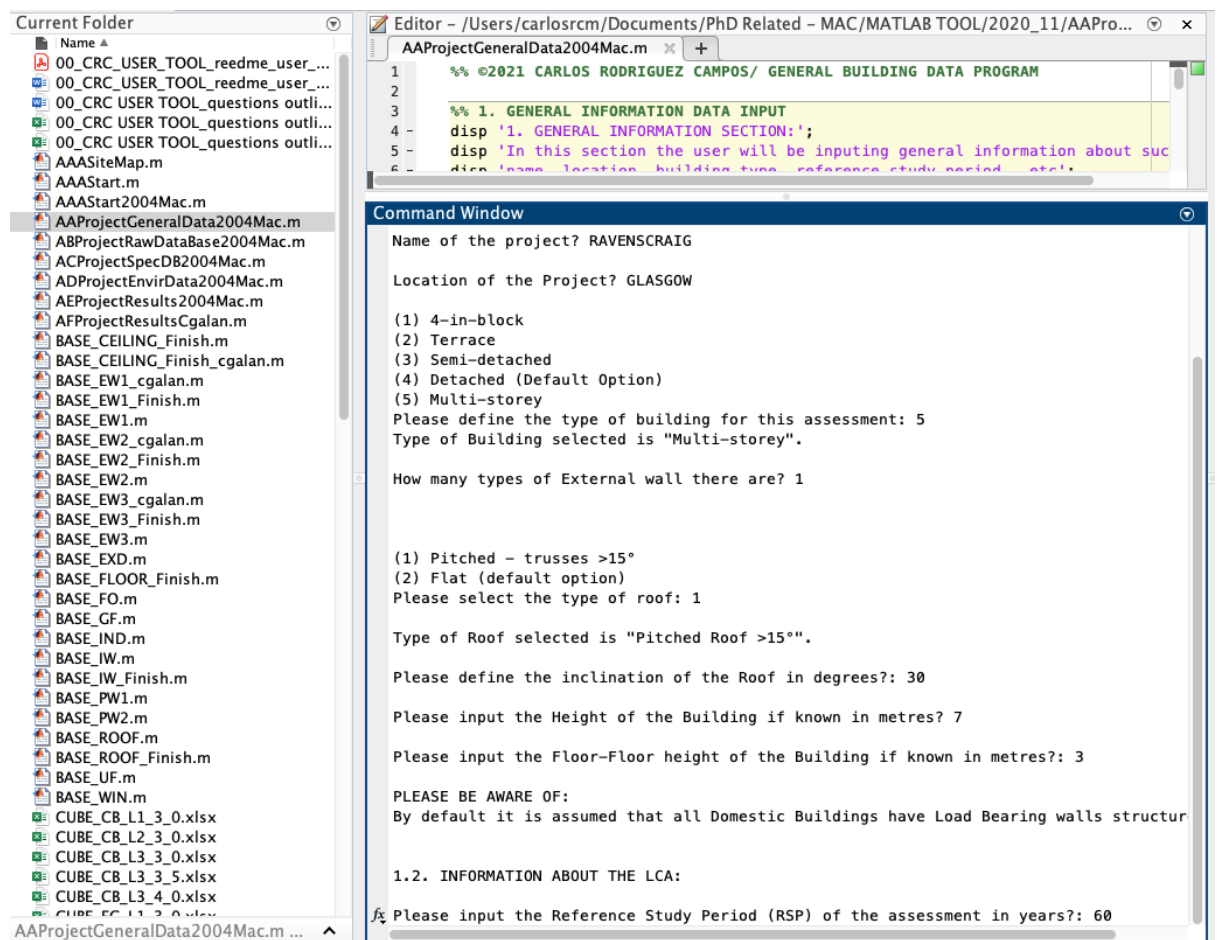
Figure 5.9: user interaction with Matlab calculation tool. RSP input by the user.

5.5.   (2) Loading the environmental database

Once the general information about the project and the building measurements have been either define by the user or gathered from an existing excel file, the environmental database needs to be loaded within the calculation tool.

Although all processes and source of data used will be explained along this chapter, this section focuses on the environmental data boundaries which the proposed methodology will be based on.

The environmental database used within the tool refers to the manufacturing embodied energy and carbon, of building products used within the building, by sqm. This is, impacts from stages A1 to A3 of the Life Cycle and its has been created with information from the I.C.E database and EPDs.

This A1-A3 information is then used, along with information from other sources, to compose all the algorithms and calculations involved in the tool. All different sources of information involved within each of the LCA stages considered are summarised as follows:

Table 5.3: Data collection process

LCA Stage		Source of information
Manufacturing & Construction	A1-A3 Manufacture	ICE 2.0 [101, 102] + EPD's
	A4 Transport	Own Tool+Gov UK DEFRA[103]+EN 16258[104]
	A5 Installation	Machinery fuel use + BRE Wastage Rates
Use	B4 Replacements	Life Expectancy book [105] +own tool calculation
	B6 Operational Energy	SAP certificates + CIBSE Guide-F [106]
End-of-use	C1 Demolition	Literature + Wastage Rates from BRE
	C2 Transport	Own Tool + Gov UK DEFRA [103] + EN 16258[104]
	C3 Waste Processing	Wastage Routes from EU-28 report [107]
	C4 Disposal	Disposal rates from BRE plublication [108]
Beyond Life Cycle*	D1 Incineration	Incineration Rates from BRE
	D2 Recycling Potential	Recycling Rates from BRE

* not include in the scope of this thesis. Part of the future work

5.5.1.   Environmental database within the tool

The environmental data comes from the I.C.E database and EPDs, as mentioned before. It is common to find these and other databases having environmental impacts expressed by unit of mass of product, such as $KgCO_2e/Kg$ and MJ/Kg. This means that, on a common LCA process, all products involved need to be converted to mass so unitary impacts are then matched with the total amount of mass of product to get a final net impact for each indicator considered.

The issue comes when talking about buildings for which quantities and measurements are often given in square metre (m^2) or linear metre (m) which, additionally, are much more common figures for non-expert's users.

This is the reason why this calculation tool uses an environmental database express by unit of measurement (impact/m^2 or impacts/m) rather than by unit of mass (impact/Kg) for both impact indicators considered. It also makes easier when performing a preliminary evaluation at the initial project status.

Hence, an initial conversion process is needed for this tool's database in order to get environmental information of building products into an easier-to-understand form and operate with "indicator by unit of measurement" (indicator/m^2 or indicator/m).

5.5.1.1. Indicators: unit conversion

This unit's conversion is possible using density and thickness properties of each construction material. All thicknesses are given by default, except for materials in which the user needs to select from certain given thicknesses such as insulation o some finishes. The density of each material is taken from the ICE database or manufacturer information. A detailed list of all materials used in the tool with both units can be seen in "Appendix B – material database".

The initial conversion means getting "Indicator/m^2" from "Indicator/Kg". It makes possible to have the simplified LCA (SLCA) unit from any original environmental database which is a feature seeked for this thesis as part of the transparency achieved. Unit conversion is explained with more detail in "Appendix A – unit conversion".

Compound products or elements, such us a complete fabric wall or different types of foundation, which involve different materials with specific quantities, are difficult to convert directly. So that, they will have an additional initial calculation process before including them into the tool's database with the unit format that is required.

In any case, for a large number of products, a direct conversion was possible using a defined thickness and the material density.

After this necessary conversion process for materials, elements and compound products, the database has been divided into families of products and a list with all of them has been produced and included into a Matlab program file. The material families considered are the following, although all families and materials can be seen on APPENDIX B: MATERIAL DATABASE:

- Cement & Mortar
- Clay & Ceramics
- Concrete
- Insulation
- Gypsum related
- Timber products
- Finishes
- Windows
- Doors
- Others

5.5.1.2.   Compound materials calculation

However, there are some known materials or elements composed by two or more materials, i.e. timber I-joists which are made of timber OSB and plywood or a brick wall which is composed by bricks and mortar. In this case of composite materials, a final figure for environmental impact by unit of area is also needed in order to keep the simplicity of this PhD method. For this purpose, all materials involved need to be calculated separately and then added in order to get a unique overall figure which could be by metre and then converted by sqm, or by sqm directly. This calculation will be explained with a single brick wall example. The same process is used for others composite materials involved in this research. More in-depth calculation for composite materials could be seen in "Appendix A – compound materials".

Although material's unit and composite materials have a straightforward conversion for there are some materials that require additional assumptions. These assumptions are taken in advance and there will be no environmental options (by the time this PhD work is finished) for the user to select. This is the case of assumptions taken for the timber and concrete products. They are explained as follows:

5.5.1.3. Timber products

Environmental data for timber products is taking into consideration the worst possible manufacturing scenario. The proposed database contains EE and EC from fossil fuels and from the biomass. This is assuming that the biomass is not carbon neutral. This assumption is possible when considering timber products from non-sustainably managed forests. When considering all or some timber products from sustainably managed forest then the environmental impact due to the biomass could be avoided as it would be considering those impacts as carbon neutral.

In addition, none of the environmental data, within the simplified methodology, related to timber products include the effects of carbon sequestration during the growing of the trees process or the biogenic carbon storage within the timber itself. Inclusion or exclusion of sequestered carbon is a very complex process which is out of the scope of this research project. However, the database is made in such a way that when accurate data regarding these processes became available and easier to quantify, it could be easily updatable. Although being out of the scope, calculation for carbon sequestration of timbre products could be found on "Appendix A – timber products"

5.5.1.4. Concrete materials

In case of in-situ reinforced concrete products, the assumptions are made for the type of material used. The environmental impact data used for this material has different figures depending on the compressive strength designation and quantity of steel used [101] in the concrete to reinforce it. More detailed calculation in regard of concrete could be found on "Appendix A – concrete products".

These combinations are defined by default within this simplified method being part of the possible future work, after this thesis, the extension of the user options regarding this matter. We´ll explain some of the default options adopted as follows:

a) In-situ concrete

It is assumed that all in-situ concrete used for the assessments will be 20/25Mpa of compressive strength designation with 100Kg of steel per cubic metre is used. Future options such as different compressive strengths and steel quantity for reinforcement will be studied.

b) Pre-cast concrete

It is assumed that all pre-cast concrete used for the assessments will be 20/25Mpa of compressive strength designation with 80Kg of steel per cubic metre is used. Other pre-cast concrete specification could be part of the future work as well.

c) Concrete blocks

It is assumed that all light pre-cast concrete blocks used for the assessments will be 8/10Mpa of compressive strength designation while the dense pre-cast concrete blocks will have 12/14Mpa of compressive strength designation.

5.5.2.   Non-environmental data calculation

As it was introduced previously on this section 5.5, despite the environmental database of materials, which is needed for the matching process of building elements and environmental impacts, there is other non-environmental information also needed when considering all processes involved within the complete building life cycle.

Even though it has been called as non-environmental data, since its primary source was not related to such data directly, this information is used to produce environmental impact results that are not only related with the manufacturing impact of materials. This is the case of time-related characteristics such as service life expressed in years, and consumption figures from energy or fuel used for the operational stage or the density and thickness used for the unit´s conversion. Also, it will be involved in such a data the percentage of material wasted on site, or demolition wastage quantities.

Those figures, assumed within the tool for certain process, will somehow be converted to impact indicator figures to include those impacts to the corresponding stage of the assessment.

This non-environmental information will be used for the calculation algorithm, in junction with the environmental impact A1-A3, to produce the complete impact figures for all LCA stages that will be explained on sections 5.5.2 and 5.7. But they are inputted at once within the tool program file.

This complete database has been developed in such a way that the information is easily updatable or changeable in case the user has more confidence with any specific material's impact, as it can be seen on the LCA Database section of the Appendix D.

5.5.2.1. Number of replacements

This is a time-related characteristic for which direct calculation could be applied using the building RSP and material Required Service Life.

Each material has a required service life (RSL) which comes from the manufacturer's guaranteed time of them or, in case not specified, from the "Life Spectancy Book" for this thesis. After its service life, materials or elements need to be replaced which add more energy and carbon consumption to the building life cycle.

Replacement has been argued for many experts as a difficult figure to be stablished with a formula. This is because replacements of large areas usually take longer periods of time to be finished, hence they are not a punctual action, as explained within the green guide [109].

However, in order to simplify this process for this assessment the number of replacements for each material is calculated following the method establish by EN 15978:2011.

Once the RSP is defined by the user, replacements are calculated dividing the required service life (RSL) of each material by the RSP and rounded to the next upper entire number. Then number of replacements results resting 1 (the actual first construction) to that number.

$$N_R = \frac{RSP}{RSL} - 1;\ Being\ always\ \frac{RSP}{RSL} \geq 1$$

Eq. 1
(Number of replacements)

When no manufacturer information was available, information for number of replacements is taken from the Green Guide to specification database of materials or expert consultation [105].

The number of replacements obtained from this section will multiply the material or element of the building and these impacts will be allocated within the corresponding LCA stage B4. These replacements affect mostly to finishes or decorative parts such as wall paints, tiles or external elements such as cladding, windows and doors. Main structure parts of the building often have the same or bigger ReqSL than the building itself.

5.5.2.2. Transport loads

This section explains how the transport impacts is calculated using freighting vehicles transport data [103] and fuel environmental figures from current standards. Final environmental units used for this methodology proposed are "indicator/m2 of material transported", following the same units used for building measurements and database of materials.

Environmental impacts due to materials transportation are calculated using an ad-hoc transport's program for this simplified methodology. This program excludes transport of persons to and from distribution centres and any packaging material. It covers the impact due to transportation by different freighting vehicles of road transport; hence the fuel usage within the transport distance according to EN 16258 [104]. It also takes into account the percentage of load against the total capacity of that specific vehicle [110]. Part of the possible future work will extend these calculations to air and train freight transport too.

There are two substages in which transport environmental impacts take place directly, transport "Gate to site" LCA-A4 and "site to landfilling" LCA-C2, within the proposed calculation tool. Transport from manufacturing gate to trading point (if different) is not considered due to the difficulties of getting accurate figures for each material.

However, as it was explained in Chapter 3, there is always some wastages during construction and those amounts of materials need first to arrive to site and them leave the site work and get to landfilling sites. Those transports are also taken into account within this methodology and allocated to LCA-A5 stage according to EN 15978 [3].

Transport also occurs when replacing some building elements. Bringing the material to site and bringing the waste material removed from the building to landfilling sites. These replacement's transport load is also considered within this methodology calculated from number of replacement values and they are allocated to stage LCA-B2.

Regarding the transportation tool performance, the user won't need to select the distances for each material or stage since a default option is predefined with the most common combination. This is 50 miles, or 80km, for gate-to-site transport (A4 stage), and the double for site-to-landfilling site (C2 stage). These distances will be applied to all materials involved within the assessment. This is made in order to achieve the simplification intended for the non-expert user, although those distances are able to be changed within the Matlab code on the "LCA-Transport" program file.

However, the user will need to define the type of vehicle that will be used and applied to all materials. Having the type of vehicle defined, the tool will get its fuel consumption and CO_2 emissions related per mass transported automatically and will convert that information to indicator by m^2 using the thickness and density of each material.

Type of vehicles available for this simplified tool are the following:

Table 5.4: type of freighting good vehicles

Type of vehicle		Type of fuel
Heavy Good vehicle	Rigid >3.5 – 7.5 tonnes	Diesel
	Rigid >7.5 – 14 tonnes	
	Rigid >14 – 17 tonnes	
	Rigid >17 – 25 tonnes	
	Rigid >25 tonnes	
	Artics (>3.5-33 tonnes))	
	Artics (>33 tonnes)	
Vans	Class I	Diesel or petrol
	Class II	
	Class III	
Modern train	Passengers	Fuels/Electricity
Container ship (coastal)	Cargo	Fossil fuels

Although more detailed calculations with a clear example, regarding environmental impacts of each type of vehicle and possibility could be found on "appendix A - transport loads", as it is a complex task with lots of combinations, depending on the type of vehicle imputed by the user, an ad-hoc spreadsheet programme included on the Matlab tool has been developed and integrated for a correct calculation even though the Matlab tool does not use it in all the possibilities of selection for simplicity and user-friendly purpose.

For load mass transported, it is considered that real cases are that freighting vehicles are first full by volume than by weight. This is the reason why for A4 transport impact, the emission figure for the vehicle selected is obtained from the 50% loaded scenario. For the C2 transport impact, however, the emission figure is from the 100% loaded scenario for the vehicle selected by the user.

5.5.2.3. Installation and demolition loads

Construction environmental impacts considered for these stages within this methodology come from two different sources. The first one would be the fuel used for the machinery during the building and fit-out process gathered from literature about energy used within construction process [111]. That fuel used has energy and emissions associated.

The second one is the fact that construction processes produce on-site waste from almost all materials involved. This means that i.e. for 1m2 of brick's wall is actually needed more than 1m2 due to breakages and errors or damaged items. That extra quantity of material considered also need to arrive to the building site even if they won't be used for the actual building itself and will be considered waste and directed to final disposal.

Hence, it will need to get out the building site, and will have transport impact plus the impact obtained for the disposal process considered. The impact due to "gate to site" and "site to landfilling" transport of this extra amount of material needs to be allocated within this construction section, LCA Stage A5, and not within the Transport A4 substage.

The construction wastage routes rates are obtained from BRE [108] and industry experts reports. For this simplified methodology, it is assumed that the waste produced on-site will go directly to landfilling sites on the ratio considered for each type of material. These ratios are indicated on the APPENDIX B: MATERIAL DATABASE.

These assumptions are supported by different studies such as construction activities and environmental impact evaluation carried out by various universities [111] for which some reference KPIs could be obtained, as well as some site studies [62, 112], for which specific data from the monitoring process were obtained. Some of the KPIs resulting from that literature review are the following.

- Excavation assumed by m3 of building. It could also be obtained by m2 (GIA). This reference could be used in case no excavation information comes with the project assessed.
- Installation process impacts by m2 (GIA) of building. Following RICS rules of measurement.
- Demolition process impacts by m2 (GIA) or by m3 of building demolished.

These KPIs could be updated periodically, as the energy and resource spectrum used in construction changes.

For this methodology the following EE and EC impacts are considered:

- Installation process [113, 114]:
  - o Electricity: assumed 25 kWh/m^2 (GIA) for the installation. This figure results on 90 MJ /m2 (GIA) and 7.65 KgCO$_2$e/m^2 (GIA).
  - o Diesel: assumed 3.5 L/m^2 (GIA) of diesel used from machinery involved. Meaning 126 MJ/m^2 (GIA) and 9.345 KgCO$_2$e/m^2 (GIA).
  - o Waste is calculated from the wastage factor from each material involved.
- Demolition [62, 115]:
  - o Embodied carbon impact is assumed to be 3.4 KgCO$_2$e/m^2 (GIA) [115].
  - o Embodied energy is assumed to be 10 kWh/m^2 (GIA) resulting on 36 MJ/m^2 (GIA).
  - o Waste disaggregation process is assumed to happen on-site by man-force, helped with machines. So that, waste already gets out of the construction site sorted by type of material.

Although these indicated benchmarks are used for the thesis project, other possible construction impacts benchmarks are available, also from the literature. That is the case of Kellenberger [114] and the benchmark table for construction and demolition impacts calculated by m3 of material constructed. This is the method used for the "Cube Building" simulation performed within the validation process of this projects which will be explained on the following chapters.

5.5.2.4. Operational energy use

Operational energy use is largely applied for consumption predictions within the built environment. For these predictions, detailed developed energy modelling software are often used. In case the energy demand has not been calculated upfront, with one of the energy current tools, then the proposed simplified tool calculates it using the UK government energy benchmarks available in CIBSE Guide-F [106]. It Is not the intention to get similar results as developing the energy tools, they will be used as a reference knowing that they are not as accurate as energy modelling studies.

These benchmarks are given in two different scenarios: typical and good practice values as the following tables shows:

Table 5.5: Operational Energy demand values from CIBSE Guide-F **[106]**

Source	Good Practice	Typical Values	Unit
Electricity	44	79	kWh/m^2
Natural Gas	247	417	

However, as it was said, this PhD does not intend to have the most real use-phase energy consumption values (they can easily be adapted depending on the building assessed), figures from this UK guide are compared with household energy consumptions in order to evaluate the accuracy and validity of these numbers within the tool.

These benchmarks are given in $kWh/m^2/year$. If we think on a 70sqm household with 2-3 users, we would have a yearly consumption of around 3.080 kWh of electricity and 17.980 kWh of natural gas for good practice and 5.530 kWh of electricity and 29.190 kWh from natural gas for typical values. Figures from good practice are within the assumed average consumption within the UK from [116] and from energy suppliers statistics [41, 117]. However, each building and case could have different figures which could be inputted on the tool, if known.

To properly add these figures to the building impacts within this tool, units are then converted from kWh per sqm and year to $MJ/m^2/year$ and $KgCO_2e/m^2/year$ for energy and carbon emissions respectively in order to be able to operate with them. This last conversion also depends on the energy source considered.

On the process of getting these new units, we need some conversion factor, which changes throughout the years, depending on the energy source used for the consumption: using fossil fuels, renewable or non-renewable resources. In other words, obtaining natural gas or electricity to a household has not the same environmental impact per kWh consumed. Conversion details are explained in "Appendix A – operational energy use".

After the appropriated unit are gained, impacts by year are multiplied for the RSP in order to get LCA figures for B6.

It is known that the data considered within the tool, when no energy model has been performed, could be appear somehow old. In any case, as it has been mentioned before, the intention is not to simulate the energy modelling tools but only be able to calculate the impacts of 60 years of operational data given a fixed consumption or demand per year.

5.5.2.5. End-of-life considerations

End of life scenarios assumed within this tool involve the following processes:

- Demolition
- Transporting from site to landfilling site
- Waste processing on those landfilling sites.

For demolitions impacts, assumptions and figures indicated on previous section 5.6.5.3. are applied. As it was mentioned previously, waste processing is assumed to happen on site by man-force within this calculation tool. Hence, no impacts are allocated for this task [118].

For transport impact from site to landfilling site, after the demolition was happened, are indicated on section 5.6.5.2.

Impact coming from the waste processing within this tool only applies to the process necessary to sort out and eliminate the material that has been sent to the landfilling site.

It is also assumed that all percentage of each material diverted from landfilling start a new impact route allocated on module D, which is no part of the scope of this thesis.

However, the rest of material which is not diverted (vast majority nowadays) are assumed to go to landfilling sites, for which processes such as internal transformation and covering are needed. For these processes environmental impact could calculated by mass of product processed. Since the mass of the building materials, that are not diverted from landfill, could be calculated, these impacts could be obtained [108]. They usually come from fuel usage from machinery on the landfilling site [118] and some carbon emissions from chemical products used on that site.

In order to get the quantities of materials sent to landfilling site, a percentage of "waste to landfill" is applied to each material considered on the assessment. Those percentages can be seen on the Appendix B: Material Database. Then, the quantity of material calculated within the building is multiplied by that percentage, resulting on the quantity of material sent to landfilling site and treated. Hence the impact of that treatment.

Within this tool, embodied energy and carbon impacts for this process [119] are assumed to be 0.33297 $KgCO_2$/kg and 0.01280 $KgCO_2e$/Kg of waste processed respectively.

5.5.3.   Loading the database within the LCA process

The way in which the Matlab tool loads this database is simply by executing the corresponding program file, saving the variables of each of the materials that compose the database in the "workspace" of the evaluation.

These products, and all the non-environmental information, will be used to compose the construction elements that will be defined by the user with the following main Matlab program file.
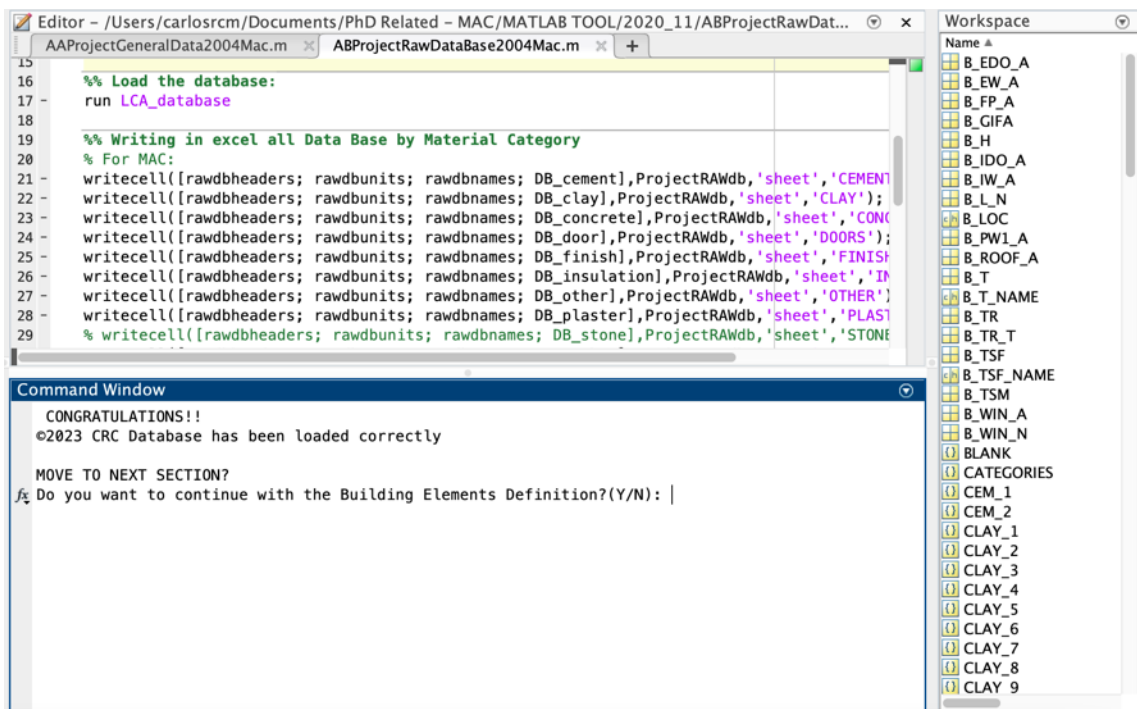
Figure 5.10: screenshot of the Matlab tool having loaded the database and asking the user to move to the next main program file

5.6.   (3) Specific building elements definition

At this point of the evaluation, the Matlab tool has already loaded information about the building measurements and a complete list with all available materials for the construction elements definition, including environmental and non-environmental information.

This definition is a process in which the user will be interacting with the tool the most. As indicated before, the program files will be prompting questions that will be answered by user. Answer will be based on the selection made from different options that will indicate tipping within the command window a certain letter "A" to "E" or number "1" to "8", depending on the case. Options comes according to the database extension of possibilities for a domestic building.

This Matlab Tool's architecture, in order to define the Building Elements and its materials involved, is in line with the New Rules of Measurement (NRM) set by RICS [100] and its classification system by building element [115]. The tool allows the user to choose between different material options for each element, which would result on the definition of each part of the building involved on the LCA. Some options are already set up by default in order to get the simplicity soughed, but user can always select the most appropriate for the case. The order in which the user will be defining the construction elements involved will be the following:

Table 5.6: tool's order for building element selection, from RICS 2017**[115]**

Level 1: group	Level 2: element	Insulation option
Substructure	Foundation	No
	Ground floor	Yes
Superstructure	Upper floor	No
	Roof	Yes
	External walls	Yes
	Internal wall	Yes
	Party walls	Yes
	Windows and external doors	No
	Internal doors	No
Internal finishes	Internal walls	-
	Ceiling	(only acoustic)
	Floors	-

5.6.1.   How the proposed tool assigns physical description

Once the building measurements are defined and loaded within the tool, the user will define each construction elements following the order described before.

With all layers and materials involved, the building elements will be automatically compiled for the building. Layer selection within the tool go from down to upper parts for horizontal elements and from out to inner parts for vertical ones.

The general rule when for the user to select any building components within the tool is the following:

1. For each building element:

   a. Selection if that element is insulated or not (if option available).
   b. Selection of insulation material and thickness (if insulated option is selected).

After insulated/not insulated option is selected, then the elements' layers are defined selecting all materials involved in each one. It is assumed that insulation is in between two other layers, even if for environmental impact purposes would not be necessary.

   c. Selection of main component, or structure component (such as type of joist for floors or main wall material)
   d. Selecting outer layer (upper part if floors or external cladding for external walls)
   e. Selecting the inner layer (for external walls, since it is assumed as cavity walls)

2. for all building elements

   f. Selection of internal finishes

After all building elements are defined, an .xlsx file will be created, called "BASELINE_Spec.xls" with all project's specifications by element. Those specifications will contain the basic data about RSL, thickness and embodied energy and carbon for manufacturing stages A1 to A3.

Regarding the insulation materials, the database currently has the most common insulation materials, available to be selected. However, it would be possible to enter special elements if there is any more specific environmental data about the insulation material being used.

Table 5.7: Insulation Material's Thicknesses Options

Insulation	Thicknesses (mm)			
	80 (cavity)	100	150	200
Wood Fibre	N	Y	Y	Y
Mineral Rock wool	N	Y	Y	Y
Mineral Glass wool	Y	Y	Y	Y
Expanded Polystyrene	Y	Y	Y	Y
Natural Insulation (hemp)	Y	Y	Y	N
Cellulose Insulation	Y	Y	N	N

As mentioned, the order in which the user will define the building elements of the building will be the one described on the previous table 5.3. Boundaries and limitations for these elements will explained with more detail in the following sub-sections.

5.6.2. Substructure

This section defines the boundary conditions that the proposed LCA will consider for when selecting the foundation system and the lowest floor of the project assessed.

5.6.2.1. Foundation selection

There are two different types of foundation options available for this methodology: concrete raft and concrete strips systems. Thicknesses and composition of foundation elements have already been pre-calculated and averaged by m^2 of domestic building construction, bearing in mind that these are probably the most difficult task for a non-expert user.

To ease the user experience and obtain the accurate quantities of materials, environmental impacts due to the considered foundations have been calculated separately and the resulting average impact per sqm of each one has been entered into the database.

For this to happen, both types of foundations have been calculated in detail using one of the case study project and then converted to an average impact by sqm of that project's footprint area, which is the impact indicated on the database. This way, the user will be able to evaluate any project with any footprint area and will be applied the average foundation impact evaluated in detail.

For both types, an average thickness of a hypothetical material layer has been calculated to get the same impact that the material has in the real foundation calculated in detail for

a specific project. Then that thickness and impacts have been entered into the database for all materials involved within any foundation type.

Both foundation options assume that brickwork walls 500mm high are set up on the concrete strips alienated with the upper load-bearing walls of the building. Double brickwork is placed under external and party walls (If any) and single brickwork under internal walls.

A) Concrete Raft 500/300mm

The raft option consists on a in-situ reinforced concrete slab 300mm thick with a thicker section of 500mm under the load-bearing walls lines. Then brickwork walls 500mm high are set up on the concrete strips alienated with the upper load-bearing walls of the building. This option can be summarised as follows:

Layers and materials taken considered in this option are the following:

Table 5.8: raft foundations components

Layers	Material	Thickness	Unit
1	In-situ reinforced concrete	300*	m
2	Single brick wall (102.5mm)	-	m^2
3	Double brick wall (215mm)	-	m^2

* average thickness is calculated for a given footprint area

B) Concrete Strips 600x400mm + compacted gravel

This second option consists on in-situ reinforced of 600 x 400mm concrete strips under every load bearing wall projected and compacted gravel between them 500mm thick. Layers and materials taken considered in this option are the following:

Table 5.9: concrete strips foundations components

Layers	Material	Thicknes	Unit
1	In-situ reinforced concrete	300*	m
2	Sand & Gravel	200*	m
3	Single brick wall (102.5mm)	-	m^2
4	Double brick wall (215mm)	-	m^2

* average impact by sqm is calculated for a given footprint area
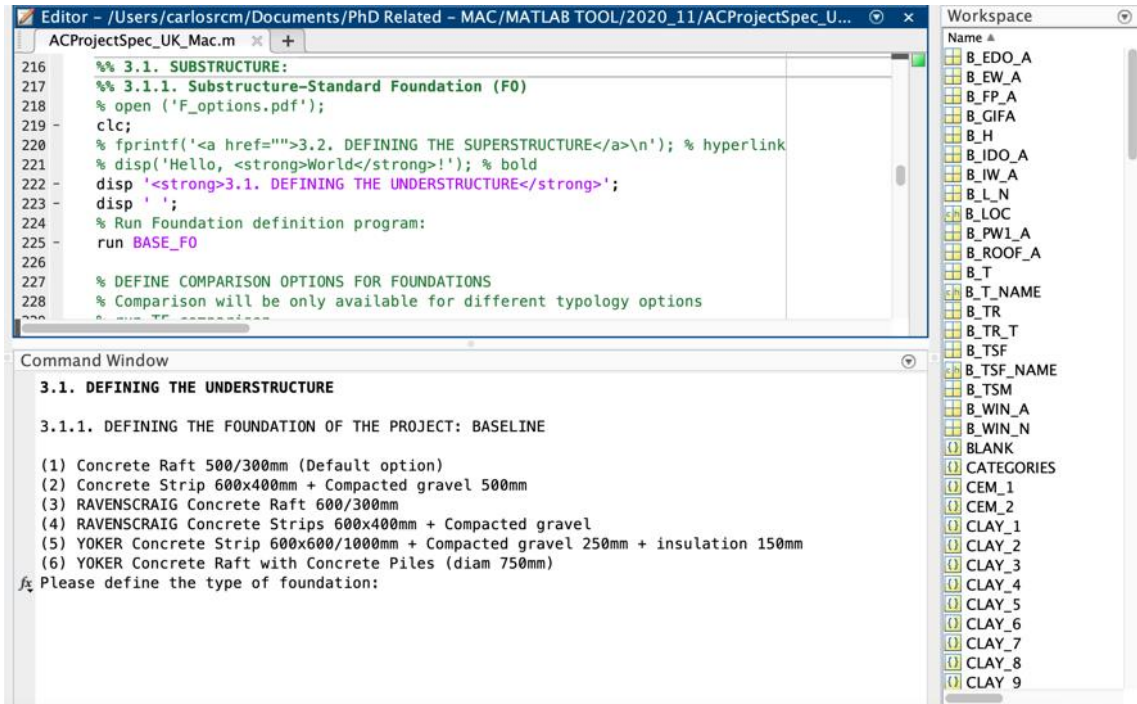
Figure 5.11: screenshot from the Matlab Tool when defining the type of foundation for the project

5.1.1.1. Lowest floor (Ground floor – GF)

Again, this floor could be insulated or not. This element consists on a main structural material (options explained below), with 9mm OSB sheets on it and then an internal finish selected by the user.

Structural part of this element will be selected from the following:

Table 5.10: structural element for ground floors

Option	Material	Height
1	Timber I-joists @400mm	250mm
2	Pre-cast 20/25 Mpa concrete joist	250mm
3	Metal joist	250mm

1. Timber I-joists @400mm. They are made of 45x45 plywood base and head with a 9mm OSB sheet aligned vertical. A Total height is considered at 250mm. Separation between them is 400mm.
2. Concrete Pre-cast Joists: they are made of pre-cast 20/25Mpa concrete. Also they would be 250mm high.

3. Metal Joists. Made of IPN 250mm S275JR steel.

Timber I-joist   Pre-cast concrete joist   Metal I-joist
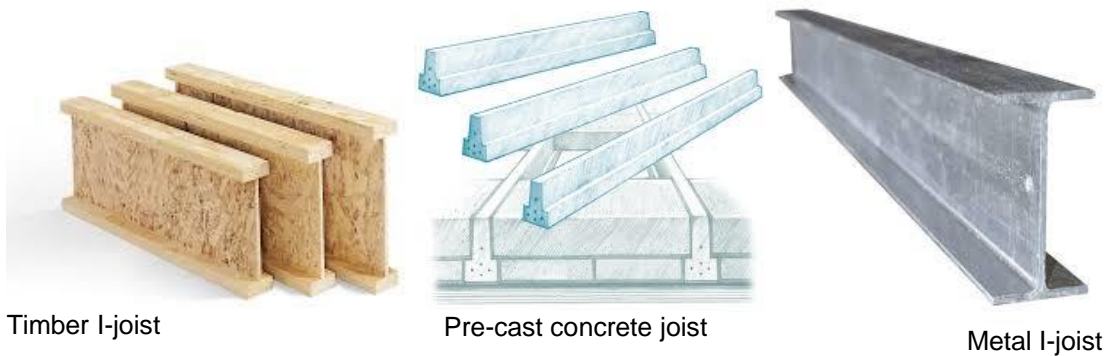
Figure 5.12: types of joists for floor's structure selection
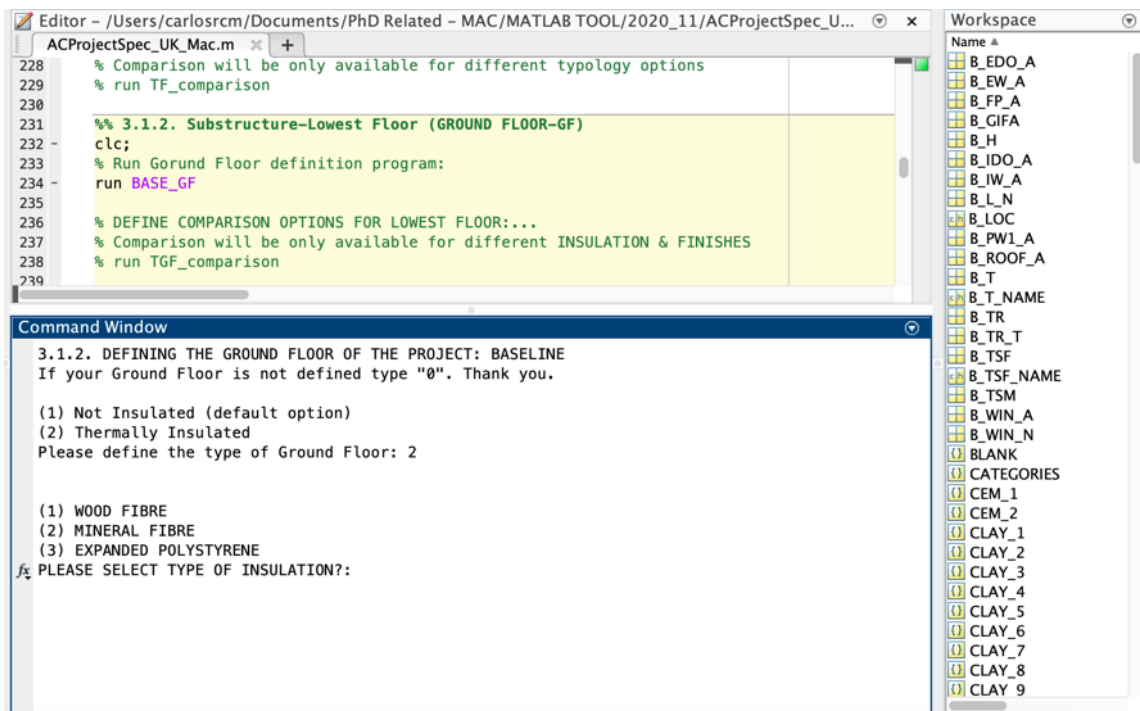
Figure 5.13: screenshot of Matlab tool when defining the insulation material for ground floor.

5.6.3.   Superstructure

Superstructure refers to all building elements above the ground floor level except for the internal finishes which will be explained in a separate section.

5.6.3.1. Frame

For this method, structure frame is assumed to be load-bearing walls since the methodology's scope is social domestic projects. Hence there is no options available for the user to select a different one. Part of the future work would possibly adapt this range of frames, but it would complicate the tool rather than adding simplicity to it, which is the aim.

5.6.3.2. Upper floors

It is assumed that "upper floors" involve all floors above the ground floor level and below the roof, for which there will be separate options. Upper floor structure options will be the same as per Ground floor options explained before. The only exception is that upper floor material's selection doesn't have the thermal insulation option since it is an internal element. However, it may have acoustic insulation options for extra comfort between floors that might belong to different apartments. This insulation option could be added with the ceiling definition.
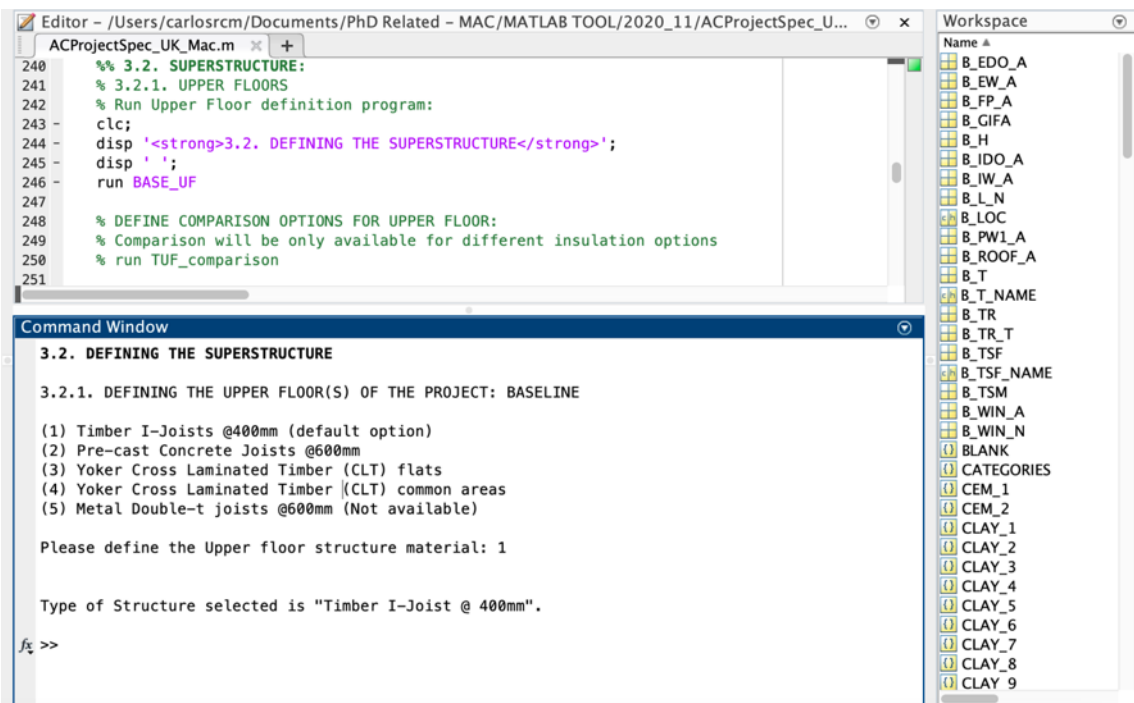
Figure 5.14: screenshot of Matlab tool when defining structure material for upper floors

5.6.3.3. External Walls

It is assumed all external walls are cavity walls, having the user to define internal and external leaves. The insulation can be fitted on the external leaf, the internal one or in the cavity that will always be 80mm thick (it does not influence the environmental impact, but it does get involved for the iteration and optimization process). Options for the structural part of each leaf are the following:

Table 5.11: External wall structural element

Option	Material	Thickness (mm)	
1	Single brick wall	102.50	mm
2	Single soft concrete block	100.00	mm
3	Single dense concrete block	100.00	mm
4	Timber studs 50x100mm @600mm + plasterboard	70.00*	mm
5	Light Metal Studs 50x100mm @600mm + plasterboard	70.00*	mm

* thickness does not apply. Impact calculations are made from compound materials and a figure by sqm is obtained. More detail for calculations on "Appendix A". Summary of environmental figures of all materials can be found on "Appendix B"

For external walls there will be also an external finish added to the external leaf selected, included on this superstructure section. External finishes could be selected from the following options (future work would be extend those options):

Table 5.12: external wall finishes

Option	Material	Thickness (mm)	
1	Render and paint (2 coats)	0.20	mm
2	Brick slips (made of clay)	0.55	mm
3	Slate slips (attached with nails)	12.00	mm
4	Metal cladding (aluminium)	0.55	mm
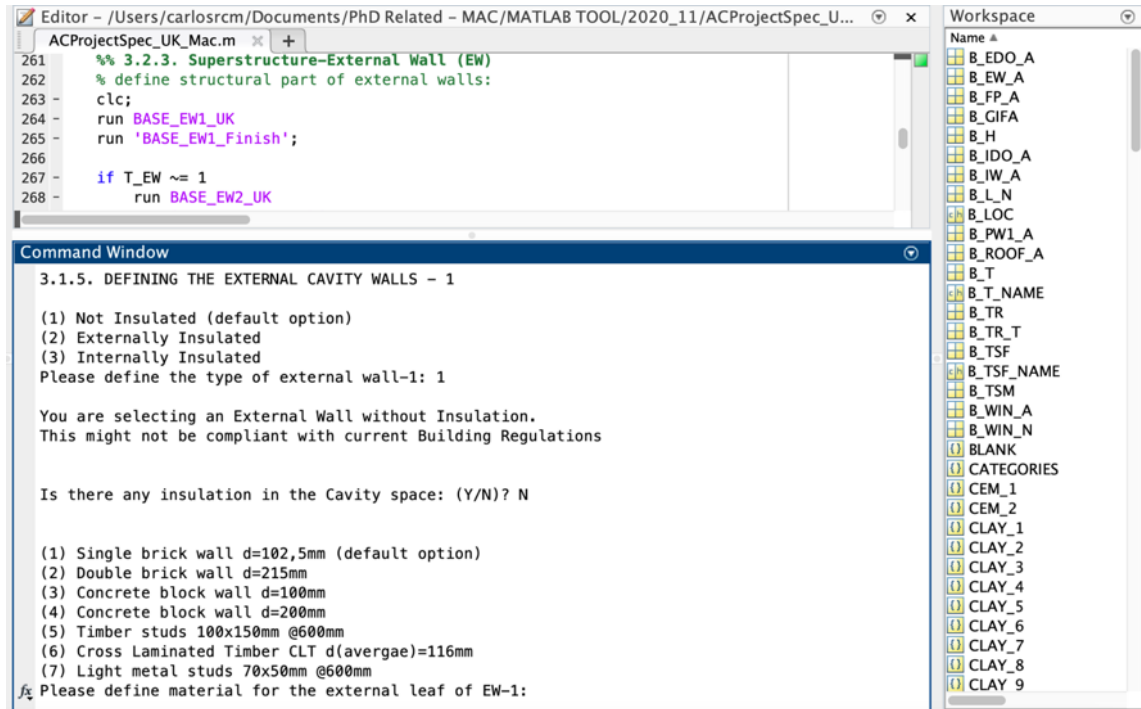
Figure 5.15: screenshot of Matlab tool when defining the external leaf of the external walls of the project

5.6.3.4. Windows and external doors

Windows and external doors will be selected from some predefined types and then applied for square metre and matched with building measurements. More calculation details are shown on "Appendix A". Windows options are the following:

Table 5.13: External windows and doors

Option	Frame material	Glazed
1	Solid timber	Single
2		Double
3		Triple
4	PVC	Single
5		Double
6	Aluminium	Single
7		Double
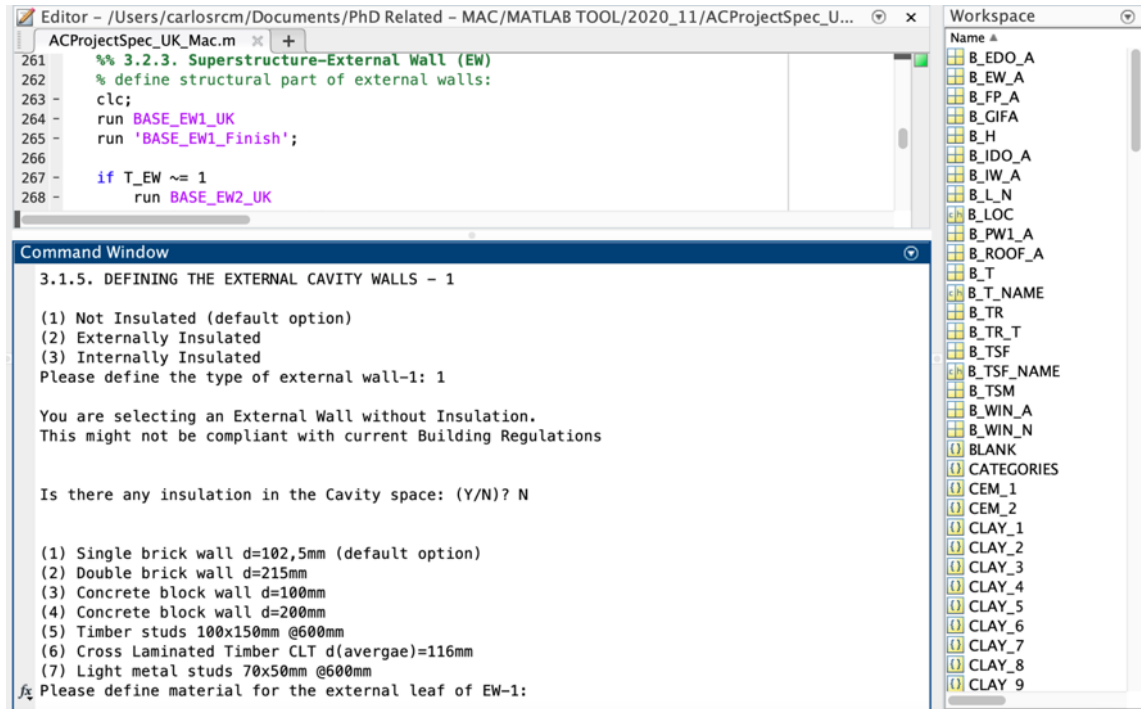
Figure 5.16: screenshot of Matlab tool when defining the external windows of the project

External door options are the following:

Table 5.14: doors: environmental Impacts

Option	Frame material	Interior
1	Solid timber	Solid
2		Battens
3	PVC	Double

5.6.3.5. Internal walls

Internal walls divide rooms of the same building or home. For that reason, it does not need thermal insulation. When selection internal walls insulated, actually it refers to acoustic insulation. If this option is selected an extra plasterboard for acoustic protection is added to the finish selection.

Structure of internal walls options are the same as per external leaf of external wall, explained before.

5.6.3.6. Partition walls

Partition walls are those that separate rooms from different homes, but they are within the same building (i.e. separating different flats). They would possible need to have a better thermal and acoustic insulation if that is the case assessed. The selection is made in the same way as per other walls, having structure possibilities as follow:

Table 5.15: External wall structural element

Option	Material	Thickness (mm)	
1	Double brick wall	215.00	mm
2	Double dense concrete block	200.00	mm
3	Double timber studs 2x50x100mm @600mm + plasterboard	130.00	mm
4	Double light Metal Studs 2x50x100mm @600mm + plasterboard	130.00	mm
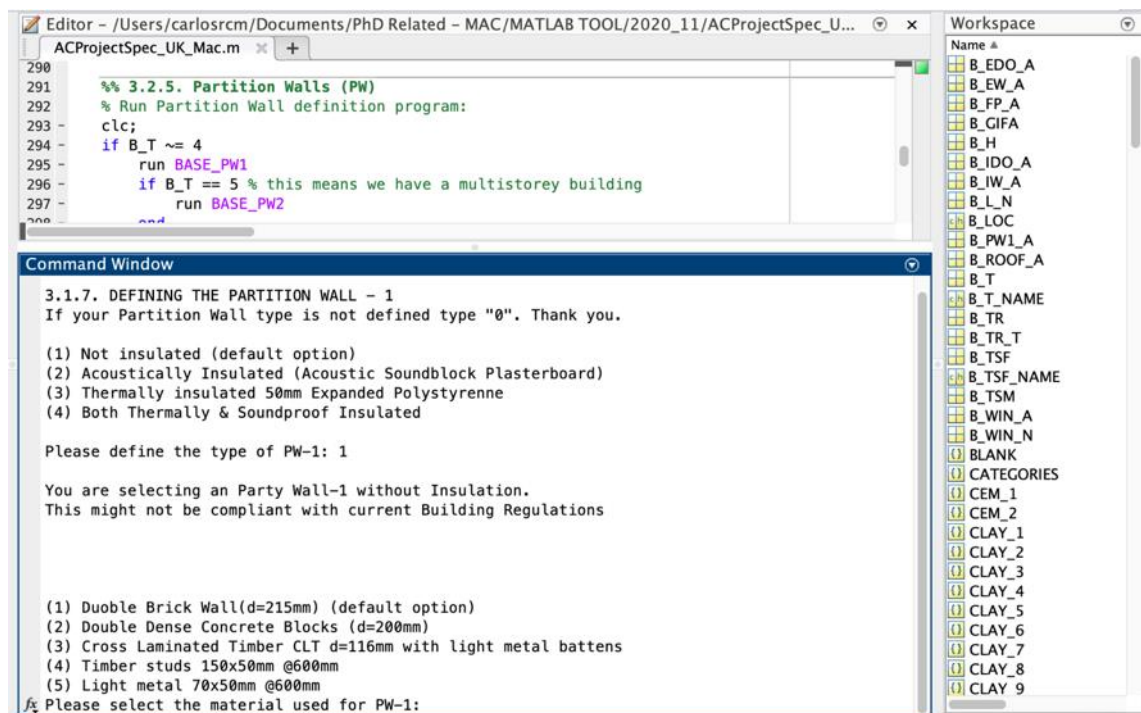
Figure 5.17: screenshot of Matlab tool when defining the partition walls of the project

5.6.3.7. Internal doors

All internal doors are assumed to be composed of 50x100mm battens for the frame and 5mm timber sheet on both sides. Then varnished or painted. Handle and possible screws are avoided in this LCA method. Calculation would be detailed on "Appendix A – Internal doors" and obtained by sqm in order to be applied to any door area defined on any project.

5.6.4. Internal finishes

Internal finishes are defined after main materials for all building elements are selected. This is how the RICS building structure definition works so that all finishes could be added to building core of assessment. Finishes could be for horizontal or vertical elements and selection will be similar to previous parts: the tool will ask the user with options available defined as follows:

5.6.4.1. Finishes to walls

There would be two variants depending on external or internal wall finish specification:

Wall finishes referring to the interior finishes will be assumed to have plasterboard attached to the wall's main structure material and before the internal visible finish (generally paint). Available options are the following:

Table 5.16: internal wall finishes

Option	Material	Thickness (mm)	
1	General paint (one coat)	0.20	mm
2	General paint (two coats)	0.55	mm
3	Water borne paint (two coats)	0.55	mm
4	Solvent borne paint (two coats)	0.55	mm
5	Wallpaper (glue included)	1.50	mm
6	Ceramic tiles (attached with mortar)	6.00	mm

5.6.4.2. Finishes to floors

Floor finishes would be applied to all floors above the foundations until the roof and would have the following options:

Table 5.17: Floor finishes

Option	Material	Thickness (mm)	
1	General carpet (stapled to timber battens)	15.00	mm
2	Laminate floor (not glued)	12.00	mm
3	Vinyl floor (glued to floors)	4.00	mm
4	Ceramic tiles (attached with mortar)	12.00	mm
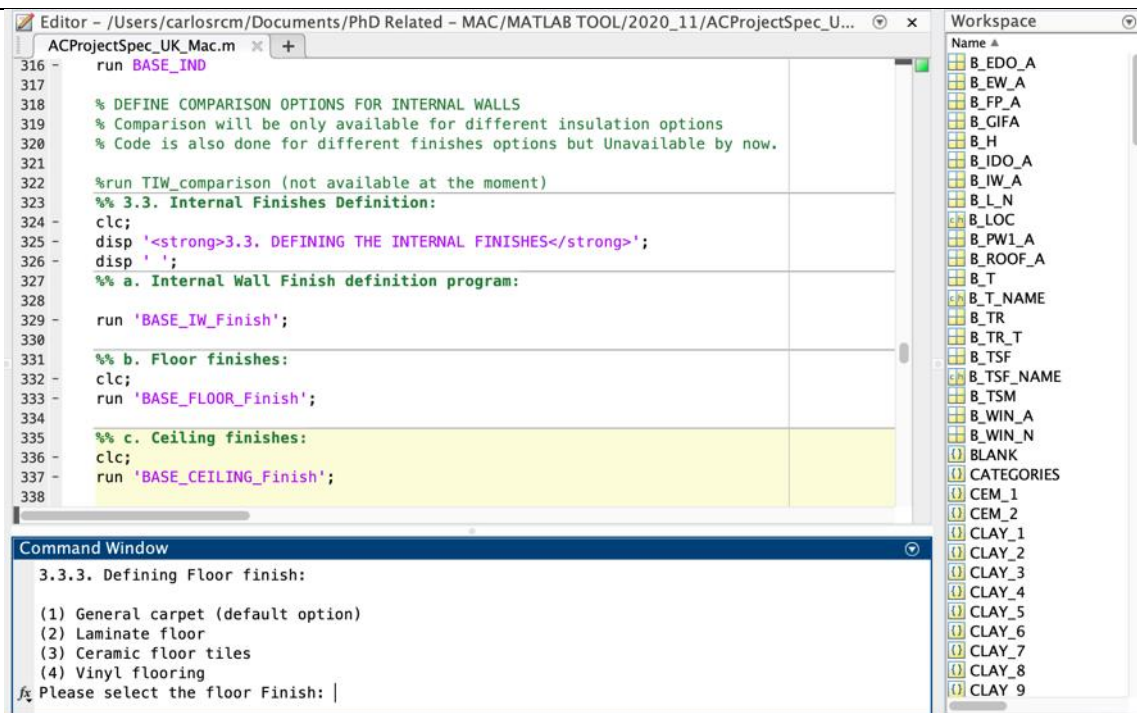
Figure 5.18: screenshot of Matlab tool when defining the floor finish

5.6.4.3. Finishes to Ceilings

For ceiling finish, this tool assumes always the same to all area defined for this element which is 1 plasterboard plank and general paint (2 coats).

5.6.5. Saving all data on an excel spreadsheet.

Once all construction elements are defined with the user inputs from the different options selected, the tool will prepare an excel spreadsheet with all construction elements specifications defined, with as many sheets as construction element have been defined. Each sheet will contain the complete table that will be needed for the following section of calculation of the environmental results.

ELEMENT	CODE	NAME	Def. WIE (m)	DENSI (Kg/m	RqSL Yea	SITE	DEM	REFURB.	MANUFACTURING A1-A3	...	OPERATION	...	END-OF-LIFE	...	Indicator
						WASTE %			MANUFAC		B4_a REPCT-MAT		C1 USE DEM		Unit
Foundations-B	CON-7_B	In-situ Concrete 20/25 RAVENSCRAIG Raft Foundation	0.4	2300	60	50	50	50	169.51						KgCO2e/m2
(F_B)			0	0	0	8	100	100	1639.8						MJ/m2
	OTHER-1	Dump Membrane	0.003	1120	60	30	0	0	4.03						KgCO2e/m2
			0	0	0	15	100	100	450.24						MJ/m2
	CLAY-5	Foundations UK Single Clay Brick Wall	0.103	1900	60	50	50	50	13.86						KgCO2e/m2
			0	0	0	5	100	100	161.99						MJ/m2
	CLAY-6	Foundations UK Double Clay Brick Wall	0.215	1900	60	50	50	50	19.24						KgCO2e/m2
			0	0	0	5	100	100	224.3						MJ/m2
								Subtotal							
								Subtotal							

Sheet tabs: FOUNDATIONS | GROUND_FLOORS | UPPER_FLOORS | ROOF | EXT_WALLS-1 | PAR_WALLS-1 | INT_WALLS | OPERATION | WINDOWS | EXT_DOORS | INT_DOORS | +

Additional column headers (row 3): C2, C3, C4, A, B4, C, TRA, WA, DISI ST, SUB ST, SUB-TOTAL

Figure 5.19: excel spreadsheet created by the tool, with all construction elements specifications selected for "retrofit Building" scenario 3

147

5.7.   (4) Tool calculation algorithm and numerical results

At this stage of the assessment, the database is fully loaded on the "workspace" of the software and the user has defined all construction elements that are now converted to variables with which the calculation algorithm is able to operate. This algorithm will calculate each of the impacts corresponding to each LCA stage and the full process can be seen on the APPENDIX D where the Matlab program file is indicated.

After all building elements are defined, consequently, the tool calculation matrix system will match all materials involved with their corresponding environmental impact (embodied energy and carbon) and, in junction with the non-environmental information, impacts for all the other LCA stages it will be calculated. This process will obtain all variables in such a way that the tool will be able to compile and show them numerically on excel spreadsheets files. Later on, with the latest program file, the tool will convert those tables to graphics results.

This main program file will execute automatically three other different program files and will create a excel spreadsheet with all numerical results. The order in which the program file operates will be the following:

- Transport calculation tool program file
- Operational phase program file
- Calculation algorithm itself program file
- Excel spreadsheet saved with all numerical results.

5.7.1. Transportation calculation

Transport impact within this tool is explained on section 5.5.2.2 and the equations followed for these calculations will be explained below. It is noted that the tool uses the 50% loading mass for A4 stage transport due to the vehicles being filled first by volume and not by mass, and 100% loading mass for C2 transport stage.

Knowing the type of vehicle used for the transport of materials, defined by the user within the tool, the other factors involved will be obtained automatically from the data loaded on the tool. This is its fuel consumption, its capacity utilisation usage percentage, how many litres of fuel are consumed for each amount of material transported. Bearing in mind that transport distances will be fixed by the tool. Therefore, the energy and carbon emissions related will be calculated and applied to all materials of the building assessment.

Fuel consumption (in L/km or L/100km) is obtained with vehicles average fuel consumption from DEFRA values [47]. It could be possible to obtain CO_2 emissions from the volume of fuel consumed but it would avoid the utilisation and load in tonnes of the materials moved. Therefore, CO_2 emissions are calculated using the "tonne*km" figures for each vehicle and load percentage. This figure is always higher than the figure obtained from the fuel's volume so that. So that last method is considered the worst-case scenario and will be always on the security side from a sustainability point of view.

This means that transport vehicle selection only needs to be done once and a two-step process will be used in order to assign and adapt that transport impact to each material option within the database. This is done using the following equations:

$$\frac{EE_{fuel} \cdot consumption \cdot distance}{load\ mass} = \frac{Indicator}{load\ mass})$$

Equation 1: transport indicator by load mass

$$\frac{EC_{fuel} \cdot distance}{load\ mass} = \frac{Indicator}{load\ mass}\ (transported)$$

Equation 2: transport carbon impact by load mass

Where:

- For EE $_{fuel}$: refers to MJ per litre of fuel based on fuel selected: petrol or diesel. From EN 16258
- For EC $_{fuel}$: refers to $KgCO_2e$ per tonne and km. Varies depending on the vehicle selected
Consumption: litres per mile or km for a specific type of vehicle

Distance: distance in km

Load mass: actual load transported; 25%, 50% or 100% of the vehicle capacity in kg.

Once transport's impact by mass of material is achieved for the distance given and the type of vehicle selected by the user, it is applied to all materials within the tool for simplicity. Then, a conversion from the "indicator/tonne" moved to "indicator/m^2" of material moved is done using the density and thickness considered on the following formula. This results on the same unit used for the rest of LCA stages. The following calculation is performed to every material within the database:

$$\frac{Indicator}{load\ mass} \cdot d \cdot Th = \frac{Indicator_{SLCA}}{m^2}\ of\ specific\ material$$

Equation 3: Transport load by square metre of material

Where:

d: density in mass per cubic metre (kg/m^3)

Th: Thickness of specific material in m.

5.7.2. Operational phase calculation

Operational benchmarks used by the tool are explained on section 5.5.2.4, having the following figures:

Table 5.18:operational energy Energy Demand (data from Cibse-Guide-F)

Source	Good Practice kWh/m^2	Typical Values kWh/m^2
Electricity	44	79
Natural Gas	247	417
Subtotals	291	496

Conversion from kWh to MJ, being both energy units, is direct, and states the following:

    (I)   1 kWh of energy = 3.6 MJ

Following the 2018 report of the UK government about GHG conversion factors [120] we obtain the following conversion factor from electrical kWh to CO_2 emissions, which is slightly higher than the same factor on 2016, but still lower than the indicated factor from 2012 [121]:

    (II)   1 kWh of electricity = 0.309 $KgCO_2$e

In the same way, in order to get the conversion factor, we use the DEFRA value when getting from natural gas kWh to CO_2 emissions is the following [103]:

    (III)   1 kWh of natural gas = 0.206 $KgCO_2$e

Table 5.19:Conversion factor from kWh to $KgCO_2$e

Source	kWh	$KgCO_2$e
Electricity	1	0.309
Natural Gas	1	0.206

Every country, or region, would have a different conversion factor when assessing the impacts from different sources of energy and processes. *i.e. USA, in 2018, the conversion factor from kWh to CO_2 emissions was of 0,99 pounds (0,449 Kg) and 0,92 pounds (0,417 Kg) of CO_2 per kWh from electricity and natural gas respectively [122].*

Using (I), (II) and (III) we get the following values used within the proposed tool for operational energy use:

Table 5.20:operational energy demand impacts

Source	Good Practice		Typical Values	
	MJ/m^2	KgCO$_2$e/m^2	MJ/m^2	KgCO$_2$e/m^2
Electricity	158.40	13.59	284.40	24.41
Natural Gas	889.20	50.88	1,501.20	85.90
Subtotals	1,047.60	64.47	1,785.60	110.31

These results are the ones which, when performing the LCA, are multiplied by the GIFA of the building, and the RSP in order to get the total impact from the use-phase of the building.

5.7.3. Calculation algorithm

Once all environmental and non-environmental impact needed for the complete assessment are loaded, the tool will execute the calculation algorithm to mix all data and obtain the environmental results for all construction elements and the building.

The complete assessment will first involve the completion of the excel spreadsheet obtained on the previous main program, having the substages impacts for each building element with the impact indicator by unit of area, which are KgCO2e/m^2 and MJ/m^2 for embodied carbon and energy respectively.

Then, those results will be matched with the building measurement loaded previously and the net environmental performance will be obtained also for all LCA stages by impact indicator and for both building elements and the complete building. This is, impacts in KgCO$_2$e and MJ which corresponds with the global environmental calculation of the building.

5.7.3.1. Transport impact calculation – Stage A4

Since the environmental impact for the manufacturing process has been already obtained from the database and the user definition of the construction elements, the first step is to use the equation 4 for each of the materials involved in all building elements. Hence multiplying the result for transport load by thickness and density of each material.

This will result on an impact by unit of area for all materials involved. And will be reflect on the spreadsheet (column K of Figure 5.19).

The process the following:

a) Transport program file has been already executed, so that a figure of indicator/Kg of material for both energy and carbon has been already obtained for either A4 stage and for C2 stage. In this step the tool only needs the first one, but both are calculated previously with the transport program, so it is already stored for the C2 stage calculation.

b) First calculation step is to obtain the Kg/m^2 of each material involved in every construction element defined. This is possible multiplying the thickness by the density of all materials.

"$Kg\_m^2 = d*thickness = (m)*(Kg/m^3)$"

c) An additional step is done to get all volume of materials because this will be needed when getting the demolition impacts using the "Kellemberger" method.

d) Second calculation step is to multiply the variable "Kg_m^2" by the A4 impact. This is done for carbon and energy indicators obtaining the impact soughed of $KgCO2e/m^2$ and MJ/m^2 of materials due to transport.

$A4_impact / m^2 = $ "$Kg\_m^2 * A4\_indicator/Kg$"

5.7.3.2. Construction impact – Stage A5

As mentioned before, on-site construction impacts is a relative complex task to quantify. It comes from the on-site wastage material and the energy and fuel consumption occurring on-site for any building process.

5.7.3.2.1. On-site wastages materials

This impact is the sum of four different processes, happening on site, with the material waste commented on section 3.2.2.2 in which it was indicated that for any square meter of brick wall it actually needs to be produced a little bit more of those products due to breakages, possible operator's errors and damaged items.

<u>A5_a) Manufacturing of the of-site waste quantity</u>

This means that for any type of material considered on the tool, a percentage of "on-site waste" (OSW_%) will be defined. It can be seen on the "site waste (%)" column.

$A5\_a = OSW\_\% * A1\text{-}A3$ impact/m^2. ($A5\_a\_indicator / m^2$)

This impact will be written on the column "L" of Figure 5.19 for all building elements.

FAMILY	CODE	NAME	Width (m)	Density (Kg/m3)	RqSL (Years)	Site waste (%)
CEMENT & MORTARS	CEM-1	Cement CEM I (Portland 94% Clinker)	0.01	1,650.00	60.00	5.00
	CEM-2	General Cement	0.02	1,650.00	60.00	5.00
	MOR-1	Cement Dry Mortar (1:5)	0.02	1,900.00	60.00	5.00
	MOR-2	Cement Mortar (1:1:6)	0.01	1,800.00	60.00	5.00
	MOR-3	General Cement Plaster	0.01	1,400.00	60.00	5.00
	MOR-4	Cement Mortar in single brick walls	0.10	1,900.00	30.00	5.00
	MOR-5	Cement Mortar in double brick walls	0.22	1,900.00	30.00	5.00
	MOR-6	Dot and Dab	0.01	1,900.00	30.00	5.00

Figure 5.20: part of the Appendix B - database showing in grey the "site waste %" column.

The calculation matrix considers that percentage and multiplies it by the manufacturing impact to obtain the result soughed. This impact will be written on the column of Figure 5.19 for all building elements.

A5_b) Transport accounting for that material to get to site.

Same process as the previous step is replicated but with the A4 figure of each material instead of with the manufacturing impact: OSW * A4 impact.

$A5\_b = kg\_m^2 * OSW\_\% * A4\_indicator/Kg \ (A5\_b\_indicator / m^2)$

This impact will be written on the column "M" of Figure 5.19 for all building elements.

A5_c) Final disposal of that extra quantity of material.

As it can be seen on the figure below, the tool is accurate designed for the wastages produce on site. It considers not only the on-site waste percentage, but also the percentage sent to landfill and diverted from landfill from that on-site waste produced.

For example, if the on-site waste for a material is 5% and the percentage sent to landfilling site from that on-site waste is the 90%, that means that the 4.5% of the material is sent on landfilling sites. That final percentage sent to landfill has been called "OSW_L_%"

FAMILY	CODE	NAME	Width (m)	Density (Kg/m3)	RqSL (Years)	Site waste (%)	% sent to: Landfill	Incineration	Recycling
CEMENT & MORTARS	CEM-1	Cement CEM I (Portland 94% Clinker)	0.01	1,650.00	60.00	5.00	90.00	1.00	9.00
	CEM-2	General Cement	0.02	1,650.00	60.00	5.00	90.00	1.00	9.00
	MOR-1	Cement Dry Mortar (1:5)	0.02	1,900.00	60.00	5.00	90.00	1.00	9.00
	MOR-2	Cement Mortar (1:1:6)	0.01	1,800.00	60.00	5.00	90.00	1.00	9.00
	MOR-3	General Cement Plaster	0.01	1,400.00	60.00	5.00	90.00	1.00	9.00
	MOR-4	Cement Mortar in single brick walls	0.10	1,900.00	30.00	5.00	90.00	1.00	9.00
	MOR-5	Cement Mortar in double brick walls	0.22	1,900.00	30.00	5.00	90.00	1.00	9.00
	MOR-6	Dot and Dab	0.01	1,900.00	30.00	5.00	90.00	1.00	9.00

Figure 5.21: part of the Appendix B - database showing in grey the "site waste %" and "landfill waste" columns.

Translated to the calculation matrix, that final percentage is multiplied by the manufacturing impact.

$A5\_c = OSW\_L\_\% * A1\text{-}A3\_impact \ (A5\_c\_indicator \ / \ m^2)$

This impact will be written on the column "N" of Figure 5.19 for all building elements.

A5_d) Transport of that material from site to landfilling site.

Transport for this last step will be calculated with the same process as the A5_b step but using the C2 transport figure instead of the A4 figure.

$A5\_d = kg\_m^2 * OSW\_L\_\% * C2\_indicator/Kg \ (A5\_d\_indicator \ / \ m^2)$

This impact will be written on the column "O" of Figure 5.19 for all building elements.

The sum of these four steps gives the complete A5 impact due to on-site waste that will be reflected on columns

5.7.3.2.2.   Fuel and energy on-site consumption.

Impacts coming from the construction process happening on-site are explained on section 5.5.2.3. from that section figures for this step are the following [113, 114]:

- o Electricity: assumed 25 kWh/m^2 (GIA) for the installation. This figure results on 90 MJ /m2 (GIA) and 7.65 KgCO$_2$e/m^2 (GIA).
- o Diesel: assumed 3.5 L/m^2 (GIA) of diesel used from machinery involved. Meaning 126 MJ/m^2 (GIA) and 9.345 KgCO$_2$e/m^2 (GIA).

This will result on CONS_IMPACT of 216 MJ/m^2 (GIA) and 16.99 KgCO$_2$e/m^2 (GIA). This figures are multiplied by the Gross Internal Area of the project to get the construction impact and it will be loaded, when writing on the excel spreadsheet, on the subtotal row instead of by material within the building elements spreadsheet shown on Figure 5.19.

$A5\_e = CONS\_IMPACT * GIA \ (A5\_e\_indicator)$

This impact won't be written on the column "P" of Figure 5.19 for all building elements, including a column of zeros instead for the sum to work properly at the end of the calculation process.

5.7.3.3. Replacement impact – Stages B4&B5

Replacements impact follow the same process as the on-site construction waste impacts. For any replacement, impacts come for the manufacturing of the material replaced, adding the extra quantity needed, transport from gate to site for the total quantity obtained, and transport plus landfilling process for the amount of material disposed.

All these steps are calculated the same way as the on-site waste impact but also incorporating the number of replacements required. These replacements are calculated dividing the reference study period by the required service life of each material.

B4_a) Manufacturing of replacement materials

Quantity of material to be replaced. In this case, the on-site waste is added to one unit.

B4_a = Num_rep * (1+OSW_%) * A1-A3_impact (B4_a_indicator / m^2)

This impact will be written on the column "Q" of Figure 5.19 for all building elements.

B4_b) Transport of that material to the construction site

Transport impact of material to be replaced is calculated with the following formula, also considering the extra quantity of on-site waste:

B4_b = Num_rep * kg_m^2 * (1+OSW_%) * A4_indicator/Kg (B4_b_indicator / m^2)

This impact will be written on the column "R" of Figure 5.19 for all building elements.

B4_c) Final disposal of material sent to landfilling site.

This material calculation considers the extra quantity produce on-site waste, to which it needs to be added the proper material replaced, coming out from the construction site.

B4_c = Num_rep * (1+OSW_L_%) * A1-A3_impact (B4_c_indicator / m^2)

This impact will be written on the column "S" of Figure 5.19 for all building elements.

B4_d) Transport of material disposed to landfilling site.

Transport of sent to landfill also considers the percentage of waste non-diverted from landfill and will be calculated as follows:

B4_d = Num_rep * kg_m^2 * (1+OSW_L_%) * C2_indicator/Kg (B4_d_indicator / m^2)

This impact will be written on the column "T" of Figure 5.19 for all building elements.

5.7.3.4. Operational impact – Stage A6

Operational impacts are calculated as explained shown on section 5.7.2. The user only needs to select the level of performance assumed for the building assessed and impact will automatically appear on the subtotal rows of the summary spreadsheet that will be defined at the end of this program file..

In case there is a detailed energy simulation made, the user will be able to input manually those impacts on the corresponding cell to evaluate all results.

A6 = Operational_impact/year * RSP (Indicator)

5.7.3.5. Demolition impact – Stage C1

As mentioned on section 5.5.2.3., demolition impacts will be the following:

Embodied carbon = 3.4 $KgCO_2e$ / m^2 (GIA)

Embodied energy = 36 MJ / m^2 (GIA)

This means that these figures will be multiplied by the GIA of each product and will be written on the summary tables, at the end of this program file instead of on the building element specification excel.

C1 = DEM_IMAPCT * GIA (C1_indicator)

5.7.3.6. Transport calculation impact – Stage C2

As mentioned before, transport calculations are made prior the execution of this calculation program file, resulting on the A4 and C2 impacts by Kg of material.

Hence, the impact due to transport after the demolition will occur will be calculated multiplying this C2 figure by the variable "Kg/m^2" of each material.

C2 = kg_m^2 * C2_indicator/Kg (C2_indicator / m^2)

This impact will be written on the column "W" of Figure 5.19 for all building elements

5.7.3.7. Landfilling impact – Stage C4

As mentioned on section 5.5.2.5. waste processing impacts on landfilling sites will be 0.33297 $KgCO_2$/kg and 0.01280 $KgCO_2e$/Kg of waste processed respectively which will be multiplied by the "Kg/m^2" variable of each material.

C4 = kg_m^2 * C4_indicator/Kg (C4_indicator/m^2)

This impact will be written on the column "Y" of Figure 5.19 for all building elements

5.7.3.8. Creating spreadsheet files for results summaries

All results will be compiled as impact by LCA global stage (A, B and C) per building area (indicator/m^2) and sums will be written on the columns "Z" to "AB" of Figure 5.19 for all building elements

With all these results will also be summarised on a separate spreadsheet with a short, extended and extra extended versions depending on the stages or sub-stages shown. The short summary version will be seen as follows:

Table 5.21: Results for both indicator: building elements

Building Element	Area (m^2)	Energy (MJ)	(%)	GWP (KgCO$_2$e)	(%)
Foundations	...	...	...	...	...
Ground floor	...	...	...	...	...
Upper floors (if any)	.	.	.	.	.
External walls	.	.	.	.	.
Internal Walls	.	.	.	.	.
Party walls (if any)	.	.	.	.	.
Roof	.	.	.	.	.
Windows & external door	.	.	.	.	.
Internal doors	...	...	...	...	...
Subtotals	-	...	-	...	**-**

Results are also obtained on the called "extended version" in which all impacts are shown by building elements and global LCA stage. The resulting table will have the following format:

Table 5.22: Results for both indicators: whole building vs LCA global stages

Indicator \ Stage	A	B	C	Total
GWP (KgCO$_2$e)	...	...	...	∑ **KgCO$_2$e**
Primary Energy (MJ)	...	...	...	∑ **MJ**

Then a more detailed table will be created showing all impacts according to every single substage considered on the LCA of the building called extra extended version. That table will have the following format:

Table 5.23: results for both indicators: whole building vs LCA sub-stages

Indicator \ Stage	A1-A3	A4	A5	B4	C1	C2	C3	C4	Total
GWP (KgCO₂e)	...	...	...	...	...	...	...	...	∑ **KgCO₂e**
Primary Energy (MJ)	...	...	...	...	...	...	...	...	∑ **MJ**

Then the user can unify all results to get a comparison of all scenarios or building assessed, even though it is not automatically produced by the tool. With those tables different scenarios and construction elements are able to be compared, using the following tables format:

Table 5.24: Results for one indicator by LCA stage – different scenarios

Scenario\Stage	A1-A3	A4	A5	B4	C1	C2	C3	C4	Total
Scenario 1	...	...	...	...	...	...	...	...	∑ **Scenario 1**
Scenario 2	...	...	...	...	...	...	...	...	∑ **Scenario 2**
Scenario …	...	...	...	...	...	...	...	...	∑ **Scenario …**
Scenario …	...	...	...	...	...	...	...	...	∑ **Scenario …**

Table 5.25: Results for both indicator: building elements

Building Element	Area (m²)	Scenario 1 Energy (MJ)	(%)	Scenario 1 GWP (KgCO₂e)	(%)	Scenario 2 Energy (MJ)	(%)	Scenario 2 GWP (KgCO₂e)	(%)	Scenario 3 … …
Foundations	...	...	...	...	...			...		...
Ground floor	...	...	...	...	...			...		...
Upper floors	.	.	.	.	.			.		.
External walls	.	.	.	.	.			.		.
Internal Walls	.	.	.	.	.			.		.
Party walls	.	.	.	.	.			.		.
Roof	.	.	.	.	.			.		.
Windows	.	.	.	.	.			.		.
Doors	...	...	...	...	...			...		...
Subtotals	-	...	-	...	-			...		...

These tables could lead to the following comparison results, made outside the matlab tool for deeper analysis of the case studies obtained.
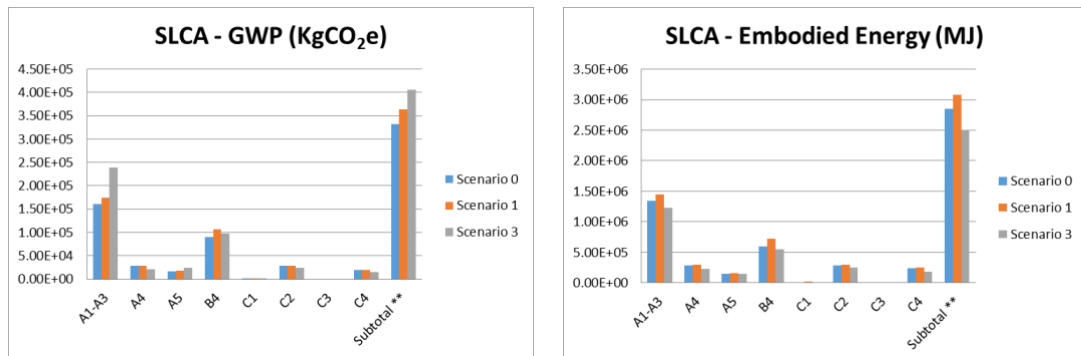
Figure 5.22: LCA proposed tool - comparison examples

5.7.4.   Saving results on excel spreadsheet file

Once all calculations are finished, a spreadsheet with all different environmental results named "ProjectENVdata_base.xlsx" will be created. This file, containing all data in different sheets for both indicators assessed show the numerical results of the complete LCA assessment of the building and it three sheets that will be seen as follows:

	A	B	C	D	E	F	G
1	Element	Area	INDICATORS				
2	Name	(m2)	KgCO2e/m2	MJ/m2	KgCO2e	MJ	
3	Foundations	150.78	305.40	3,709.79	46,048.82	559,361.42	
4	Ground Floor	150.78	493.68	2,441.73	74,436.55	368,163.42	
5	Upper Floor	150.78	476.74	1,528.93	71,883.58	230,532.36	
6	Roof	189.36	157.52	3,311.42	23,750.39	499,296.04	
7	External Walls	290.87	139.27	2,092.42	40,509.52	608,621.36	
8	Party Walls	58.58	96.17	1,082.69	5,633.72	63,423.69	
9	Internal Walls	423.84	63.99	793.36	27,123.52	336,259.57	
10	Windows	45.18	93.02	1,781.94	4,202.43	80,508.12	
11	External Doors	7.79	7.28	89.03	56.72	693.51	
12	Internal Doors	38.33	7.28	89.03	279.07	3,412.38	
13		TOTALS	1,840.36	16,920.32	293,924.32	2,750,271.88	
14							
15							

SUMMARY_S   SUMMARY_E   SUMMARY_EE   +

Figure 5.23: excel spreadsheet 1 created with the Matlab tool with results from "Retrofit building" scenario 3 evaluation.

	A	B	C	D	E	F	G	H
1	Element	Area		MANUFACTURI	USE-REPLACEM	END-OF-LIFE		
2	Name	(m2)	Indicator	A	B	C	SubTotal	
3	Foundations	150.8	KgCO2e	37,283.60	0.00	8,765.23	46,048.82	
4			MJ	447,481.18	0.00	111,880.24	559,361.42	
5	Ground Floor	150.8	KgCO2e	40,446.53	33,425.62	564.40	74,436.55	
6			MJ	204,867.37	156,091.96	7,204.08	368,163.42	
7	Upper Floor	150.8	KgCO2e	37,841.41	33,199.30	842.87	71,883.58	
8			MJ	123,977.33	95,796.54	10,758.49	230,532.36	
9	Roof	189.4	KgCO2e	15,697.10	7,307.97	745.32	23,750.39	
10			MJ	343,046.85	146,735.84	9,513.35	499,296.04	
11	External Wall	290.9	KgCO2e	28,603.54	6,593.85	5,312.14	40,509.52	
12			MJ	390,684.96	150,131.73	67,804.68	608,621.36	
13	Partition Wall	58.58	KgCO2e	3,682.57	888.23	1,062.93	5,633.72	
14			MJ	36,043.64	13,812.74	13,567.31	63,423.69	
15	Internal Walls	423.8	KgCO2e	16,234.39	6,426.52	4,462.60	27,123.52	
16			MJ	179,360.02	99,938.42	56,961.13	336,259.57	
17	Windows	45.18	KgCO2e	4,008.16	54.91	139.35	4,202.43	
18			MJ	78,112.86	616.51	1,778.74	80,508.12	
19	External Doors	7.79	KgCO2e	32.68	16.03	8.01	56.72	
20			MJ	406.00	185.28	102.23	693.51	
21	Internal Doors	38.33	KgCO2e	160.80	78.86	39.41	279.07	
22			MJ	1,997.70	911.65	503.02	3,412.38	
23	TOTALS		KgCO2e	183,990.78	87,991.28	21,942.26	293,924.32	
24			MJ	1,805,977.93	664,220.67	280,073.28	2,750,271.88	

SUMMARY_S   SUMMARY_E   SUMMARY_EE   +

Figure 5.24: excel spreadsheet 2 created with the Matlab tool with results from "Retrofit building" scenario 3 evaluation

Element Name	Area (m2)	Indicator	MANUFACTURING A1-A3	A4	A5-a	A5-b	A5-c	A5-d	A5-e	USE-REPLACEMENT B4_a	B4_b	B4_c	B4_d	B6	END-OF-LIFE C1	C2	C3	C4	SubTotal
Foundations	150.8	KgCO2e	31,157.18	3,453.78	2,257.59	225.48	1,110.57	189.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2,946.33	46,048.82
		MJ	373,384.05	38,777.82	31,639.22	2,531.66	13,783.00	1,148.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	35,252.57	0.00	76,627.67	559,361.42
Ground Floor	150.8	KgCO2e	38,465.49	222.39	1,744.68	5.55	1,570.21	8.42	0.00	160.64	34,876.76	236.87	0.00	0.00	0.00	374.68	0.00	189.72	74,436.55
		MJ	193,165.77	2,496.94	9,091.28	62.36	8,182.15	51.02	0.00	1,803.62	162,850.01	1,435.04	0.00	0.00	0.00	2,269.95	0.00	4,934.14	368,163.42
Upper Floor	150.8	KgCO2e	35,990.27	332.12	1,482.32	13.98	1,339.49	22.73	0.00	278.79	32,484.28	436.23	0.00	0.00	0.00	559.55	0.00	283.32	71,883.58
		MJ	118,570.23	3,728.91	1,383.55	156.98	1,340.46	137.67	0.00	3,130.20	90,023.52	2,642.82	0.00	0.00	0.00	3,389.91	0.00	7,368.58	230,532.36
Roof	189.4	KgCO2e	14,805.28	293.68	548.85	20.44	424.56	28.84	0.00	236.36	6,696.36	375.25	0.00	0.00	0.00	494.79	0.00	250.53	23,750.39
		MJ	318,206.41	3,297.34	21,138.82	229.54	12,758.88	174.75	0.00	2,653.80	141,808.69	2,273.36	0.00	0.00	0.00	2,997.58	0.00	6,515.77	499,296.04
External Wall	290.9	KgCO2e	24,753.04	2,093.15	1,536.17	112.58	1,014.01	108.60	0.00	228.91	6,007.45	357.48	0.00	0.00	0.00	3,526.52	0.00	1,785.62	40,509.52
		MJ	341,038.79	23,501.18	24,223.05	1,264.00	18,037.56	657.94	0.00	2,570.14	145,395.86	2,165.74	0.00	0.00	0.00	21,364.71	0.00	46,439.97	608,621.36
Partition Wall	58.58	KgCO2e	3,046.46	418.83	172.84	22.24	111.85	22.20	0.00	71.90	703.12	113.20	0.00	0.00	0.00	705.64	0.00	357.29	5,633.72
		MJ	29,111.38	4,702.45	1,845.62	249.68	1,382.25	134.52	0.00	807.26	12,319.66	685.82	0.00	0.00	0.00	4,274.95	0.00	9,292.36	63,423.69
Internal Walls	423.8	KgCO2e	13,450.65	1,758.41	820.96	97.30	594.50	107.08	0.00	520.21	5,087.26	819.06	0.00	0.00	0.00	2,962.55	0.00	1,500.05	27,123.52
		MJ	147,670.43	19,742.80	10,205.61	1,092.46	8,426.98	648.72	0.00	5,840.73	89,135.61	4,962.09	0.00	0.00	0.00	17,948.00	0.00	39,013.14	336,259.57
Windows	45.18	KgCO2e	3,953.25	54.91	0.00	0.00	0.00	0.00	0.00	54.91	0.00	0.00	0.00	0.00	0.00	92.51	0.00	46.84	4,202.43
		MJ	77,496.35	616.51	0.00	0.00	0.00	0.00	0.00	616.51	0.00	0.00	0.00	0.00	0.00	560.47	0.00	1,218.27	80,508.12
External Doors	7.79	KgCO2e	29.52	3.16	0.00	0.00	0.00	0.00	0.00	0.00	13.58	2.45	0.00	0.00	0.00	5.32	0.00	2.69	56.72
		MJ	370.57	35.43	0.00	0.00	0.00	0.00	0.00	0.00	170.46	14.82	0.00	0.00	0.00	32.21	0.00	70.02	693.51
Internal Doors	38.33	KgCO2e	145.27	15.53	0.00	0.00	0.00	0.00	0.00	0.00	66.82	12.03	0.00	0.00	0.00	26.16	0.00	13.25	279.07
		MJ	1,823.36	174.35	0.00	0.00	0.00	0.00	0.00	0.00	838.74	72.91	0.00	0.00	0.00	158.50	0.00	344.52	3,412.38
TOTALS		KgCO2e	165,796.41	8,645.96	8,563.39	497.58	6,165.20	487.44	10,071.47	1,551.73	85,935.63	2,352.57	0.00	4,032.08	1,797,376.82	14,566.61	0.00	7,375.65	293,924.32
		MJ	1,600,837.34	97,073.73	99,527.15	5,586.67	63,911.28	2,953.05	165,827.80	17,422.25	642,542.55	14,252.59	0.00	72,215.17	29,262,610.80	88,248.84	0.00	191,824.43	2,750,271.88

SUMMARY_S   SUMMARY_E   SUMMARY_EE   +

Figure 5.25: excel spreadsheet 3 created with the Matlab tool with results from "Retrofit building" scenario 3 evaluation

5.7.5. Calculation of the optimal thickness of insulation

The tool is designed to iterate and optimize some factor once the building is already evaluated. These factors are the insulation thickness for the various elements of the building, having into account the U-values for which the building should have been design.

This includes first floor construction, external walls and roof. It is not part of the scope of the thesis internal walls, external windows, or external doors.

The aim of the tool, in this step, is to indicate the optimal thickness of insulation needed, for each insulation selected on each building element considered (ground floor, external walls and roof) to get the referenced U-value from the local normative.

To get that figure, the tool calculates the U-value of each element and compare it with the reference one. Then, it can show if thicker or thinner insulation is needed to get the thermal properties for which the building should have been designed for.

If more thickness is needed, means that the project does not complies with the building regulations and, when adding more insulation will incur on a higher environmental impact.

If less thickness is needed means that the building could have been over insulated, and its environmental performance could improve when still complying with building regulations.

5.7.6.   Calculation of the optimal environmental scenario.

On the previous step, the tool does calculate the optimal thickness for the insulation option selected for each element. In this step, the tool would calculate the optimal thickness of each of the insulation options available within the database considering the U-value target.

Once all those optimal thicknesses were calculated the tool is capable of iterate several times within seconds, pursuing the optimal environmental performance to comply with the mentioned building regulations for each of those insulation options.

Depending on the general information given, each element will have an optimal insulation selection to get the lowest impact while maintaining the U-value target. The aggregation of those will have the best environmental scenario available for the user.

It is known that cost-effective measures are also to be considered when changing materials specifications throughout the building projects. Since economic factors are not part of the scope of this thesis, it is however something to consider for future development.

This way, not only environmental optimization would be achieved but also including possible monetary increments of those options. So that, having as a result the best-case scenario in terms of cost and environmental impacts.

5.8.   (5) Reporting graphical results

On the previous program file, results are shown numerically through tables and, at this stage, the tool is ready to convert those tables into graphics results shown them with and without the B6 stage. This distinction is made because the user may be only interested on embodied energy and carbon, leaving the operational impact for a more accurate energy simulation assessment, out of the scope of this thesis.

The program file starts creating all arrays of data needed for the graphs, including with any additional legend and graphic axes that will be needed for a complete comprehension of results. Furthermore, with every graph shown on the Matlab window, the user will be able to either save it or not into .jpeg format on the same directory from which the Matlab program is being executed.
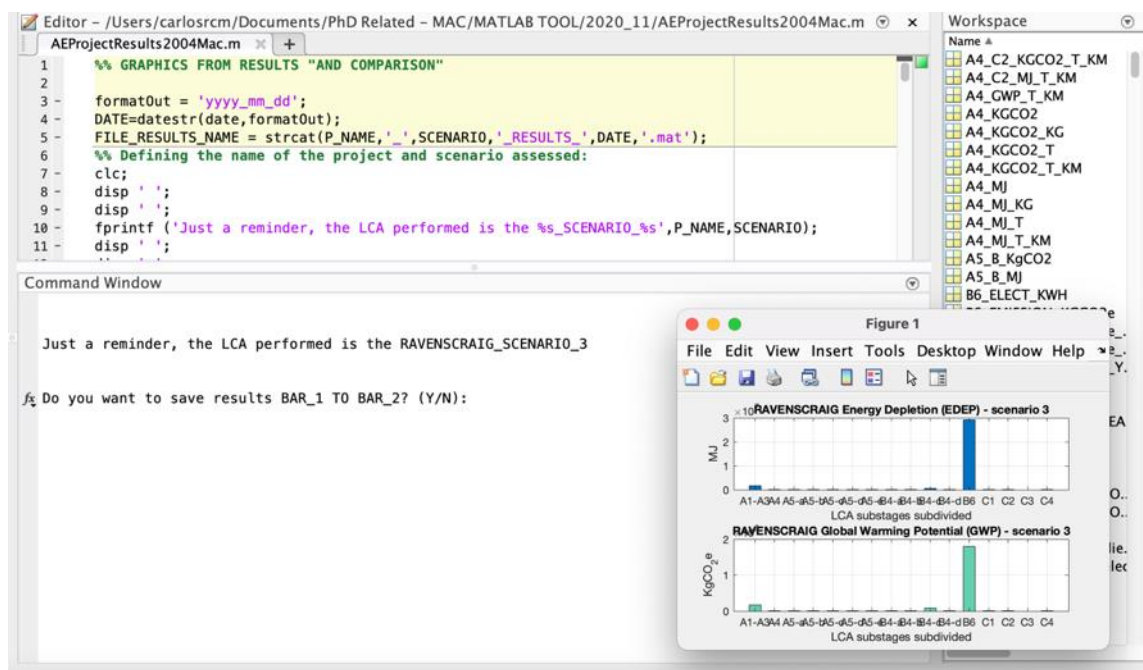
Figure 5.26: Matlab screenshot. Beginning of graphical results program file.

Graphic results will be shown as bar plots and pie charts and will be the following:

5.8.1.   BAR plots

5.8.1.1. Plot 1. Bars plot with all substages including B6

It shows two bar plots, one for embodied energy and the second one for embodied carbon.
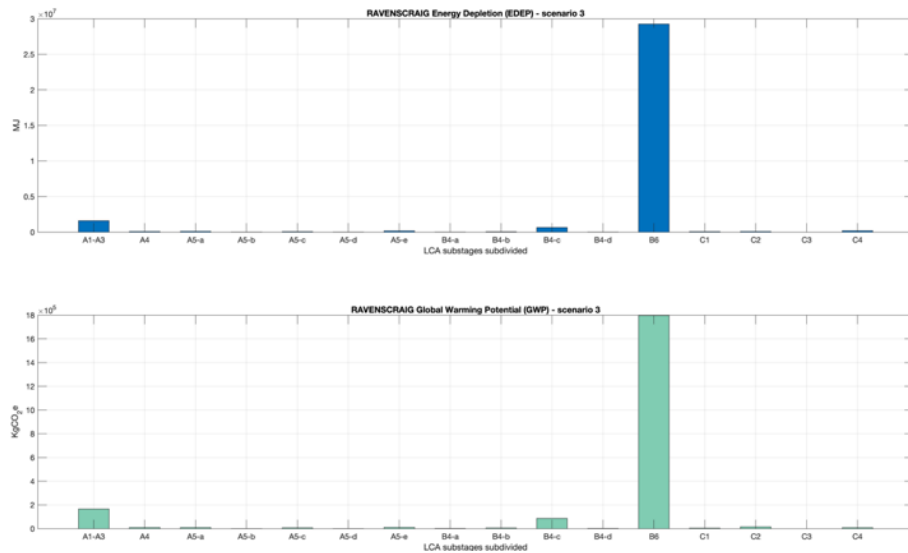
Figure 5.27: plot 1, bars graph produced by the Matlab tool from "Retrofit Building" scenario 3 evaluation. Results of all LCA sub-stages including B6.

5.8.1.2.   Plot 2. Bars plot with all stages including B6

It shows all substages grouped and global LCA stages, including B6, with four bar plots, two for embodied energy and the second two for embodied carbon.
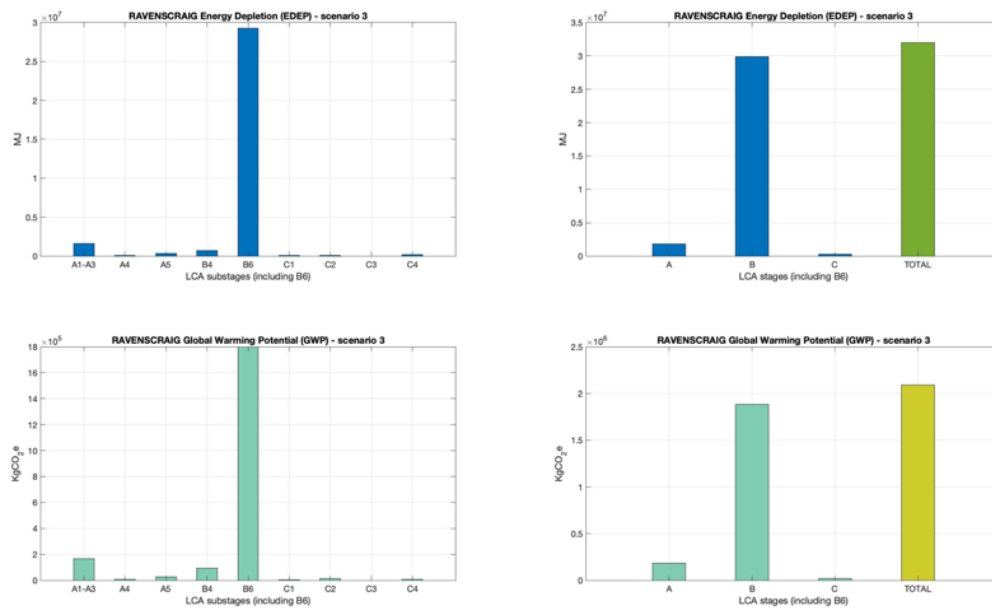
Figure 5.28: plot 2, bars graph produced by the Matlab tool from "Retrofit Building" scenario 3 evaluation. Results of all LCA stages including B6.

5.8.1.3.   Plot 3. Bars plots with all substages not including B6
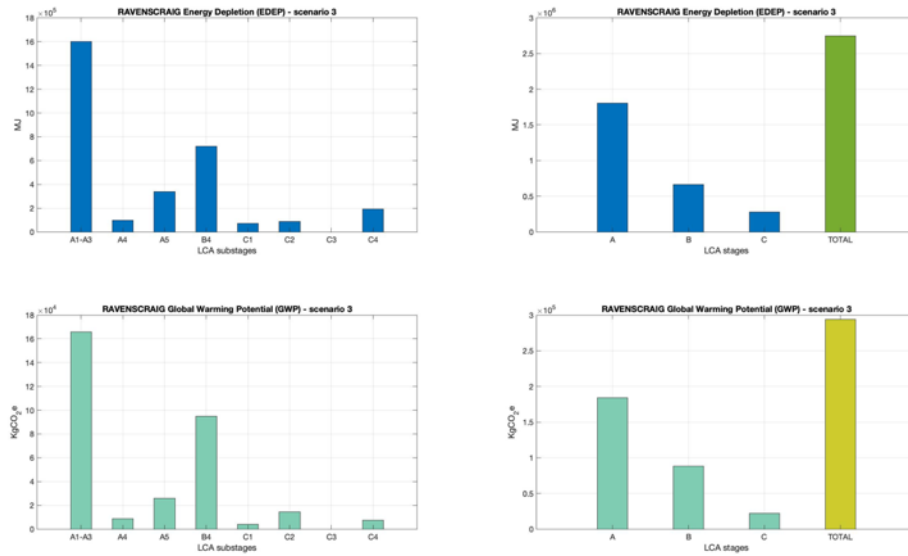
Figure 5.29: plot 3, bars graph produced by the Matlab tool from "Retrofit Building" scenario 3 evaluation. Results of all LCA stages not including B6.

5.8.1.4.   Plot 4. Stacked bar plot with and without B6

Each colour represents a different LCA stage or substage.
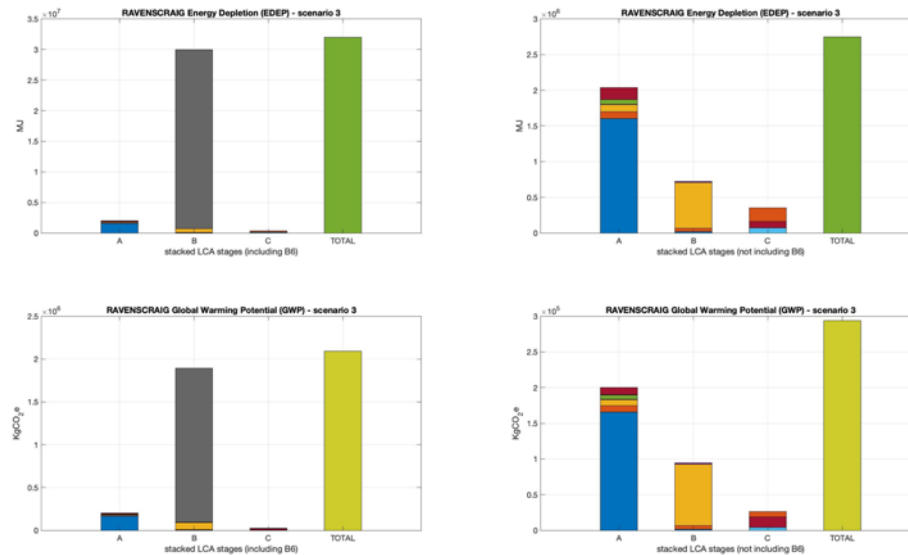
Figure 5.30: Plot 4, stacked bars produced by the Matlab tool from "Retrofit Building" scenario 3 evaluation. Results of all stages with and without B6.

5.8.1.5.   Plot 5. Combo Bar with all substages including B6.

It shows two bar plots each of which contains embodied energy and carbon results. the second one has the results grouped by LCA stage rather than with all substages.
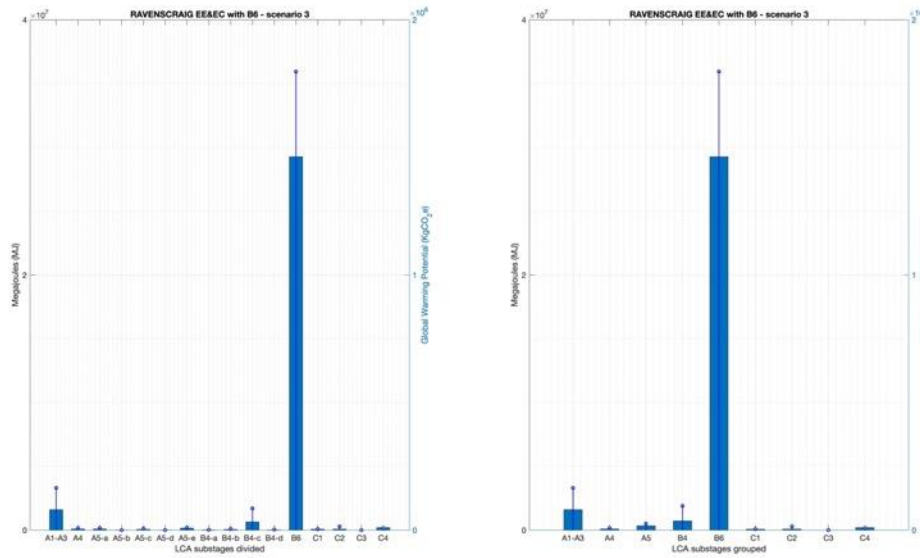
Figure 5.31: Combo bar plot 5 produced by the Matlab tool from "Retrofit Building" scenario 3 evaluation. Results of all substages including B6.

5.8.1.6.   Plot 6. Combo bar with all substages not including B6.

It shows two bar plots each of which contains embodied energy and carbon results. the second one has the results grouped by LCA stage rather than with all substages.
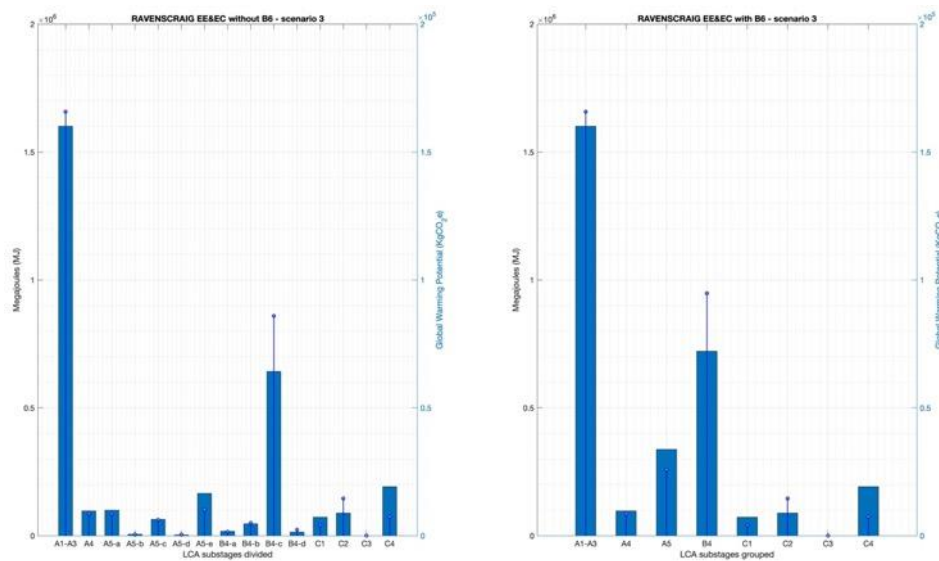
Figure 5.32: Combo bar plot 6 produced by the Matlab tool from Ravenscraig scenario 3 evaluation. Results of all substages not including B6.

5.8.2. PIE charts

5.8.2.1. Pie chart 1. All stages including B6.
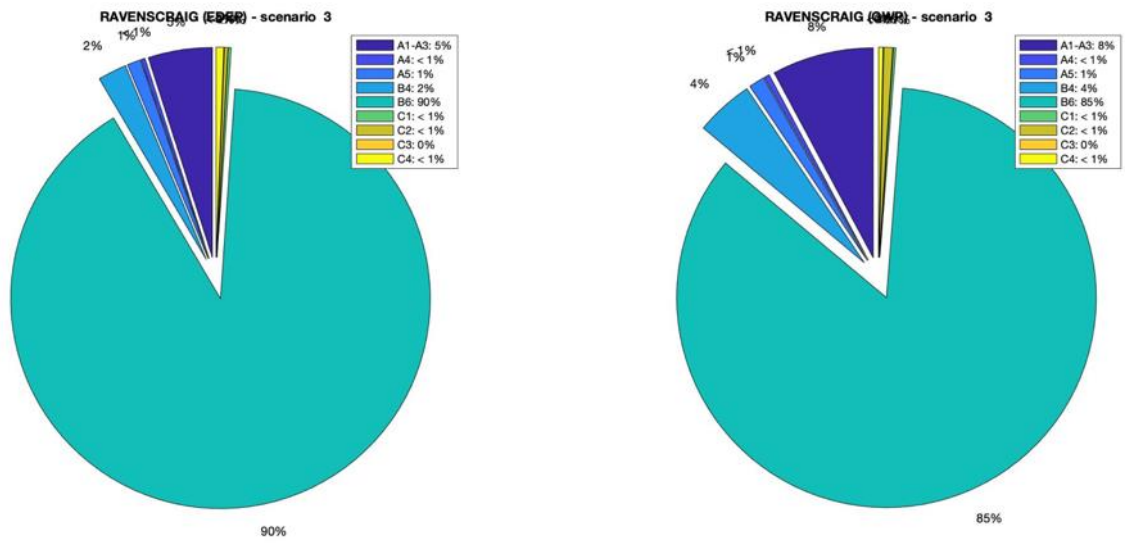
Figure 5.33: Pie chart 1 produced by the Matlab tool from Ravenscraig scenario 3 evaluation. Results of all LCA stages including B6.

5.8.2.2. Pie chart 2. Same as previous without the associated percentage to each LCA stage.

5.8.2.3. Pie chart 3. Only global stages, including B6.
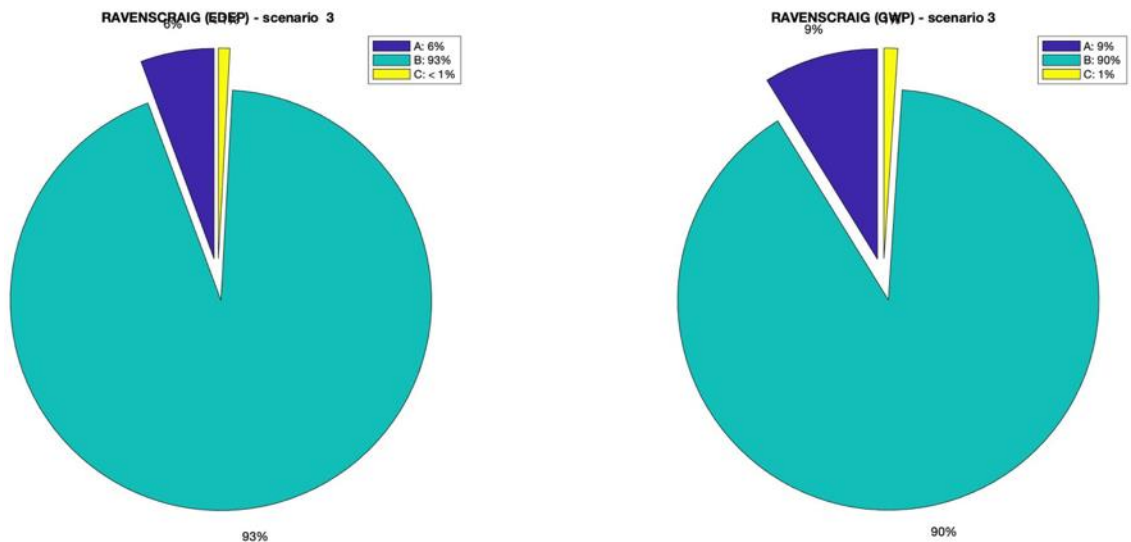
Figure 5.34: Pie chart 3 produced by the Matlab tool from Ravenscraig scenario 3 evaluation. Results for global LCA stages including B6.

5.8.2.4. Pie chart 4. Same as previous without the associated percentage to each LCA stage.

5.8.2.5.   Pie chart 5. All subtages grouped, not including B6.
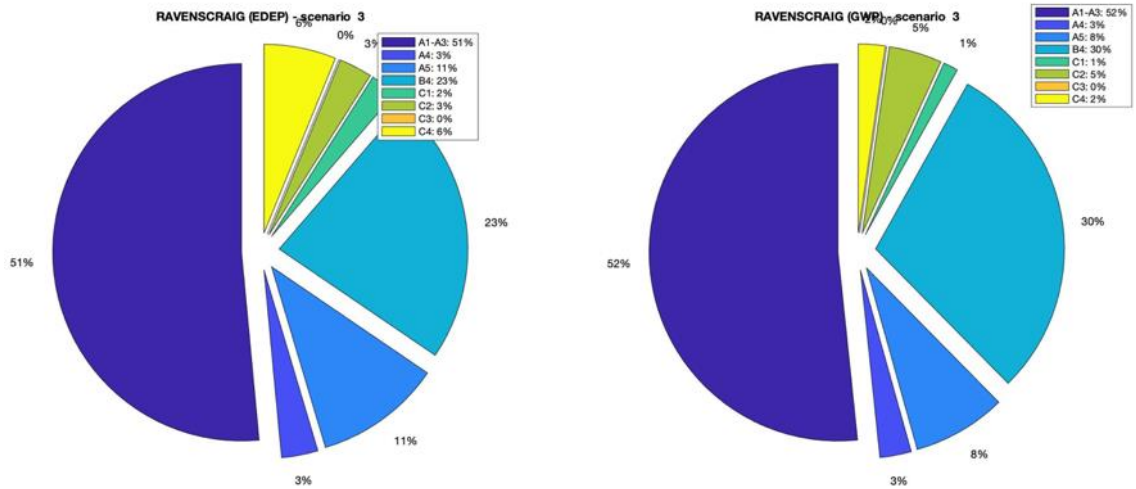
Figure 5.35: Pie chart 5 produced by the Matlab tool from Ravenscraig scenario 3 evaluation. Results for all LCA embodied stages, not including B6.

5.8.2.6.   Pie chart 6. Same as previous without the associated percentage to each LCA stage.

5.8.2.7.   Pie chart 7. Only global stages not including B6.
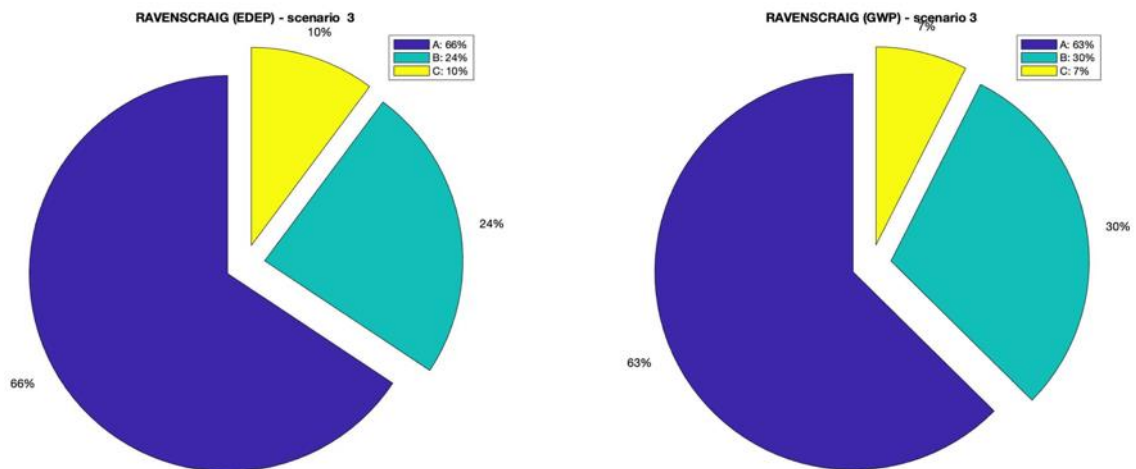
Figure 5.36. Pie chart 7 produced by the Matlab tool from Ravenscraig scenario 3 evalutaion. Results for global LCA embodied stages, not including B6.

5.8.2.8.   Pie chart 8. Same as previous without the associated percentage to each LCA stage.

Future development will allow the user to compare with other options. At the end of each element the comparison question will pop out to record different scenarios.

6

CHAPTER 6: LCA OF BUILDING SIMULATIONS

6.1.   Goal and Scope of the simulation

The principal aim is to be to perform the simulations with the proposed calculation tool in order to get the environmental impacts of the buildings evaluated using the methodology proposed, including the optimization calculation incorporated.

This process can be very iterative since the new tool must be calibrated with all different factors involved and updated at the same time that the case studies are evaluated.

The scope of this simulation process involves the environmental impacts such as embodied energy and embodied carbon from all LCA stages explained on the previous chapter, including End-of-life stage. This involves studying from "cradle-to-cave", from the materials manufacturing that compose the building elements of the domestic buildings studied including the construction processes that they require. The building elements part of the scope within the simulation process are the mentioned on previous chapters.

All materials accounting for less than 5% of the total mass of the building will be out of the scope [39] such as fixing nails or some minor adhesives…etc. It will also be out of the scope all potential furniture, equipment, facilities or its installations processes.

The simulations presented are the following:

- Cube building. It consists on a simulation of the same building evaluated using other LCA tools and already published [40].
- BRE "Retrofit Building". It consists on the simulation of four different scenarios studied at BRE Ravenscraig's innovation park, Glasgow.
- CCG Yoker housing project. Consists on the simulation of this innovative project built in Glasgow which uses Cross Laminated Timber (CLT) load-bearing walls and floors.

All case studies will be addressed in the same way, having common LCA factors and assumptions that will be explained throughout this chapter. As stated on previous chapter 5, all five calculation steps will be considered and explained, from general information of each case until results analysis. Further sensitivity analysis will be performed on the following chapter [39] where also buildings will be compared against current LCA benchmarks [123].

6.2.   Simulation assessments

In order to get direct correspondence with the explained methodology, information about the case studies will be explained in the same order as in Chapter 5.

6.2.1. Functional equivalent and RSP

As stated before, the functional equivalent will be the complete building. Thus, environmental figures will be reported as a whole given globally of by unit of area.

According to European and international standards [3, 124], for these simulation processes the RSP is been established at 60 years. However, as mentioned on previous sections, any period between 30 and 90, in 5-years intervals, would work for the tool to evaluate the environmental impact since the conversion factor would be applied if needed.

Hence, general information about the buildings used for these simulations is indicated on the following table:

Table 6.1: General Information of evaluated buildings

General Information	BRE Ravenscarig	CCG Yoker	Published case study
Name of Project	Retrofit Building	CCY CLT Yoker	Cube Building
Location	Glasgow	Glasgow	Seville
Type of Building	4-in-block	Multi-storey	Multi-storey
Number of floors	2	8	1
Type of Roof	Pitched (30º)	Flat	Flat
Reference Study Period	60 years	60 years	60 years

6.2.2. Building measurements

Building measurements are given by architectural drawings and the 3d model produced from them with graphic software (Revit). This section refers to main building elements areas to match them with the construction specifications within the projects.

From all these building elements, materials quantities involved in them are calculated using the specification of the internal parts using the methodology proposed and user-friendly tool elaborated. The building elements measurements, for both buildings, are the following:

Table 6.2: general measurements of evaluated buildings

Building Element	Retrofit Building	CLT Building	Unit
Footprint Area	154.78	550.00	m^2
*Floor Area (G.I.F.A.)	310.00	3745.00	m^2
Upper Floor Area (net)	150,78	3168.00	m^2
Roof Pitch Inclination	30^0	0	m^2
Roof Area (net)	189.36	528.00	m^2
*Gross External Wall Area	290.87	1920.89	m^2
External Wall (brick slip) net area	-	1059.36	m^2
External Wall (cladding) net area	-	861.53	m^2
External Window (net area)	45.18	656.49	m^2
External Doors (net area)	8.40	10.67	m^2
*Gross Internal Wall area	491.00	3389.87	m^2
Internal Wall area (net households)	432.42	2046.27	m^2
*Gross Party Wall area	58.58	1343.60	m^2
Party Wall area (net flat-flat)	58.58	736.55	m^2
Party wall area (net flat-close)	-	363.86	m^2
Walls in common area (net)	-	243.19	m^2
Internal Door area	46.12	130.90	m^2
Internal Door (count)	28	77	Units

* Not used for calculations. Only information purposes

Building measurements for "Cube Building" are not shown since for that evaluation only external walls are considered. They will be explained on the corresponding section within this chapter.

Complete environmental data for all building elements of each case study can be found on the respective Appendix B: Cube Building, Ravenscraig and CCG Yoker.

6.2.3. Processes considered on simulations

This section will explain the assumptions considered within the environmental simulations, of transport, installation, demolition, use and end-of-life stages for all buildings evaluated.

All scenarios adopted for the "Cube Building" simulation have been made matched with the criteria used on the published paper in order to test the proposed tool with a valid LCA method and database compliant with current standards EN 15978:2011 [3].

This PhD had access to all that criteria which is already indicated on the 2015 paper "Embodied energy of conventional load-bearing walls versus natural stabilized earth blocks" [40]. In this case stages involving the LCA of the scope of the simulation will be the same as per the paper:

- A1-A3: material manufacturing
- A4 & A5: materials transport and on-site construction
- B4: material replacements
- C2: waste transport from site to final disposal
- C4: final disposal of waste.

6.2.3.1. Transportation

For transport loads, the following assumptions have been considered and applied to all materials.

In regards of the "Cube Building" simulation, transport information has been matched with the assumptions made on the published paper. So that, same initial information has been used expecting then identical results on these stages A4 (transport to site) and C2 (transport to landfilling site). This would be explained more in detail on the chapter and the validation process.

Table 6.3: Transport assumptions for simulations

Transport		BRE Retrofit Building	CCG Yoker	Cube Building
Gato-to-site	Heavy good's vehicle	50 miles / 80 km		50 km
		Rigid (>3.5 – 7.5 tonnes)		Rigid (32 tonnes)
		50% loaden		
Site-to LF site	Heavy good's vehicle	100 miles / 160 km		100 km
		Rigid (>3.5 – 7.5 tonnes)		Rigid (32 tonnes)
		100%		

The corresponding impacts figures, by tonne*km, have been used. These figures are indicated on chapter 5 and "Appendix A – transport", for the corresponding vehicles involved.

6.2.3.2. Number of replacements

As explained before, number of replacements depend on ReqSL of each material involved on the simulation process. Life expectancy of materials can be found on appendix B.

6.2.3.3. Installation & demolition processes

Impacts for demolition processes have been explained before. However, as indicated on previous chapter, the Kellenberger table for construction and demolition impacts has been used to calculate on-site impacts for the "Cube Building" simulations. The following impacts have been considered for the simulations process:

Table 6.4: construction and demolition impacts considered

Process		BRE Retrofit Building	CCG Yoker	Cube Building
Construction	EE (MJ/m2)	179.97		1,592.50*
	EC (KgCO2e/m2)	15.98		96.72*
Demolition	EE (MJ/m2)	35.59		38.98*
	EC (KgCO2e/m2)	3.40		693.59*

 * Indicators by m3 instead of by m2

6.2.3.4. Operational energy

Operational use consumption figures have been taken from CIBSE Guide F Benchmarks [106] as explained on previous chapter 5.

Regarding BRE Ravenscraig Scenario 0, where no insulation is considered, typical practice figures are considered, due to the lack of insulation and assumption that more heating and cooling energy would be needed.

For the rest of scenarios where insulation it is considered, good practice figures are placed, as it is supposed that a better building´s energy performance would be achieved.

For cube building, in which assessment of the B6 stage is not part of the scope, no operational energy was considered.

Values used for operational stages are the following:

Table 6.5: operational energy demand from CIBSE Guide-F **[106]**

Source	Good Practice		Typical Values	
	MJ/m^2	$KgCO_2e/m^2$	MJ/m^2	$KgCO_2e/m^2$
Electricity	158.40	13.59	284.40	24.41
Natural Gas	889.20	50.88	1,501.20	85.90
Subtotals	**1,047.60**	**64.47**	**1,785.60**	**110.31**

6.2.3.5. Final disposal

Final disposal impacts considered for all simulations are explained on chapter 5 and "Appendix A – Final disposal figures"., same impacts figures as the published paper have been considered, for "The Cube Building" simulations in order to match the baseline calculation with the initial criteria of the paper, so that result could be compared accordingly. They could be summarised as follow:

Table 6.6: final disposal impacts considered

Process		BRE Retrofit Building	CCG Yoker	Cube Building
Final disposal	EE (MJ/tonne)	0.33297		
	EC ($KgCO_2e$/tonne)	0.01280		

6.3.   Cube building

6.3.1.   Building description

This case study consists on the performance of the walls LCA evaluation of a common typology building in Spain, used for domestic projects. This building characteristics are deeper explained on the published paper by Galan, Carmen et al [40]. This published paper, used as a reference for this simulation (and validation explained on the following chapter) studies a common building with one to three levels of 3m high each and three load-bearing walls 8m long. These load-bearing walls are separated between them with 3 to 4,5m spans. Hence, it also analyses results with different levels and wall's spans having a total of 12 different metric scenarios. In addition, it considers four different materials for those load-bearing walls: brick fabric, precast concrete blocks, stabilised earth blocks and in-situ concrete.

However, for this evaluation, since the primary objective is to test the proposed tool with different types of buildings and materials, the 1 level option with three different materials are considered for simulations and comparison.

Although this one level option would consider the four different spans between walls, their thicknesses remain the same for all of them. Hence, three simulations will result from the same building using three materials for those mentioned load-bearing walls: fired bricks, concrete blocks and reinforced concrete options.
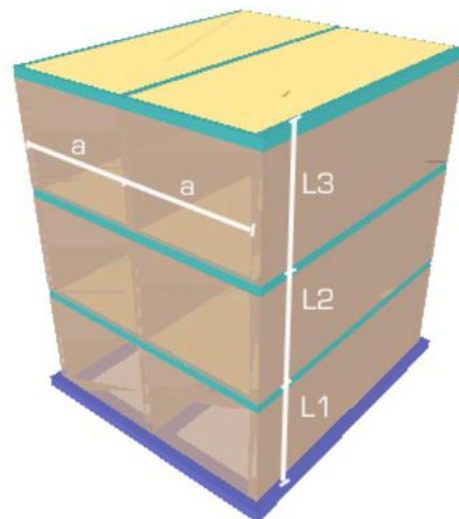
Figure 6.1: Scheme of the building analysed: "Cubic building".

"a" represents the span (from 3.00m to 4.50m). L1, L2, L3 represents the height of the different levels

6.3.2. Physical description

In this case, physical description will only affect to the load-bearing walls. Since the reference paper focuses on this parameter, insulation or any other buildings elements will not be considered.

Each load-bearing wall is 8m long and 3m high, resulting on 24m^2 of area each and 72 m^2 in total. This will be the wall area considered by the tool for environmental calculations. Walls' fabric thickness will depend on the structural needs depending on the number of levels. In this case study, only the one level option is evaluated and the following wall's thicknesses are considered for the simulation, matched with the same simulations analysed on the paper for further comparison opportunities:

Table 6.7: wall's thicknesses considered for cube building simulation

Load-bearing wall material		Brick fabric	Concrete block	Reinforced concrete
Wall	Area		Thickness	
Wall 1	24m2	0.24		
Wall 2	24m2	0.37	0.20	0.25
Wall 3	24m2	0.24		

In these simulations, the following materials are included on the tool's database in order to consider their environmental impacts:

Table 6.8: Cube building: materials considered for load-bearing walls

-	Material	Thickness	EE/m^2	EC/m^2
(No.)	(name)	(mm)	(MJ/m^2)	(KgCO$_2$/m^2)
1	Single Brick wall	240	640.99	60.63
2	Double brick wall	365	935,84	88.53
3	Concrete block	200	298.72	39.18
4	Reinforced concrete	250	688.01	81.26

6.3.3. Results

For these simulations, results are given on a spreadsheet table automatically created by the own MATLAB tool when all information needed has been inputted for each of the different scenarios evaluated.

As per all simulations performed with the proposed tool, and explained on the previous chapter, four different ".mat" files and four different ".xls" files are obtained with all information of the variables created during the simulation process. One per each step of the proposed method.

After evaluations are performed, the following tables are produced from the simulations of the tool (all three individual tables have been united in one):

Table 6.9: Cube Building simulations results obtained for all materials evaluated

Material	A1-A3	A4	A5	C2	C4	Totals	Unit
Brck wall	4,919.04	287.69	1,835.53	287.69	442.81	7,772.75	KgCO2e
	51,997.22	4,868.99	30,222.18	4,868.99	11,516.49	103,473.88	MJ
Concrete block	2,821.54	130.53	659.33	130.53	200.91	3,942.83	KgCO2e
	21,507.84	2,209.13	10,855.97	2,209.13	5,225.20	42,007.27	MJ
Reinforce concrete	5,850.72	444.97	1,831.85	403.41	606.36	9,137.32	KgCO2e
	49,537.08	7,531.02	30,161.67	6,827.54	15,770.21	109,827.52	MJ

Level 1 (all spans with the same thickness)

Table 6.10: Cube building published paper results for all materials evaluated

Material	A1-A3	A4	A5	C2	C4	Totals	Unit
Brck wall	4,919.06	287.69	1,835.01	287.69	442.81	7,772.26	KgCO2e
	51,984.59	4,869.08	30,214.23	4,869.08	11,519.20	103,468.79	MJ
Concrete block	2,821.60	130.56	659.10	130.56	200.95	3,942.77	KgCO2e
	21,507.87	2,209.63	10,851.59	2,209.63	5,227.50	42,006.22	MJ
Reinforce concrete	5,850.73	444.98	1,831.77	403.41	606.38	9,137.27	KgCO2e
	49,537.11	7,531.15	30,158.56	6,827.65	15,774.23	109,828.71	MJ

Level 1 (all spans with the same thickness)

As it can be seen, results from both, published paper and the proposed tool's simulations figures are exactly the same, only differing on decimal places with an error smaller than 0,2% between them.

These results indicate that the simulation tool of this Phd project works well and it is accurate enough to indicate valid results for building elements impacts.

6.4.   BRE Retrofit Building (RB)

6.4.1. Building description

This simulation involves the "Retrofit building" from the BRE Innovation Park at Ravenscraig, Glasgow, UK. The building involves a recreation of one of the most typical constructions within the UK, with more than 300k buildings within England only. It is a construction system used mostly in the 1950s and 1960s so they are all reaching the end-of-life stage in which they will need to either be deeply refurbished or demolish for new construction units.

As explained before, LCA has the potential to also evaluate both scenarios for the building, but this is not the aim of this research that other dissertation already studied. It has also the potential to evaluate which is the most environmental retrofit options between all possible solutions.

Figure 6.2: BRE Ravenscraig "Retrofit Building"

The building, also known as "4-in-block" typology, consists in two storeys construction with a total of four flats, two at the ground level with entrance front the main façade of the building and two at the upper level with lateral entrance's door.

The particular case of this building is that BRE wanted to propose different retrofit/upgrade options within the same building envelope, having applied different finishes acoustic and thermal insulation levels in all four flats as it can be seen from the pictures. The main idea is to try two different scenarios with two different options each depending on the potential occupancy scenario of the flats, making a total of four different variations. The left part of the building was treated as if people was living in them and then considering minimum disruption with the upgrading works. This part has external thermal insulation followed by different external finishes for front (render and paint) and back (brick slips) sides. On the other hand, the right part of the building was treated as

vacant so that internal upgrading work were possible. This part has internal thermal and acoustic insulation only in the ground level leaving the upper floor just with some thermal insulation in the roof layer. The external finish is render and paint for all this right side of the building.

External Wall 1

External Wall 2

External Wall 3

First Floor:

Flats F1 and F2

Ground Floor:

Flats G1 and G2
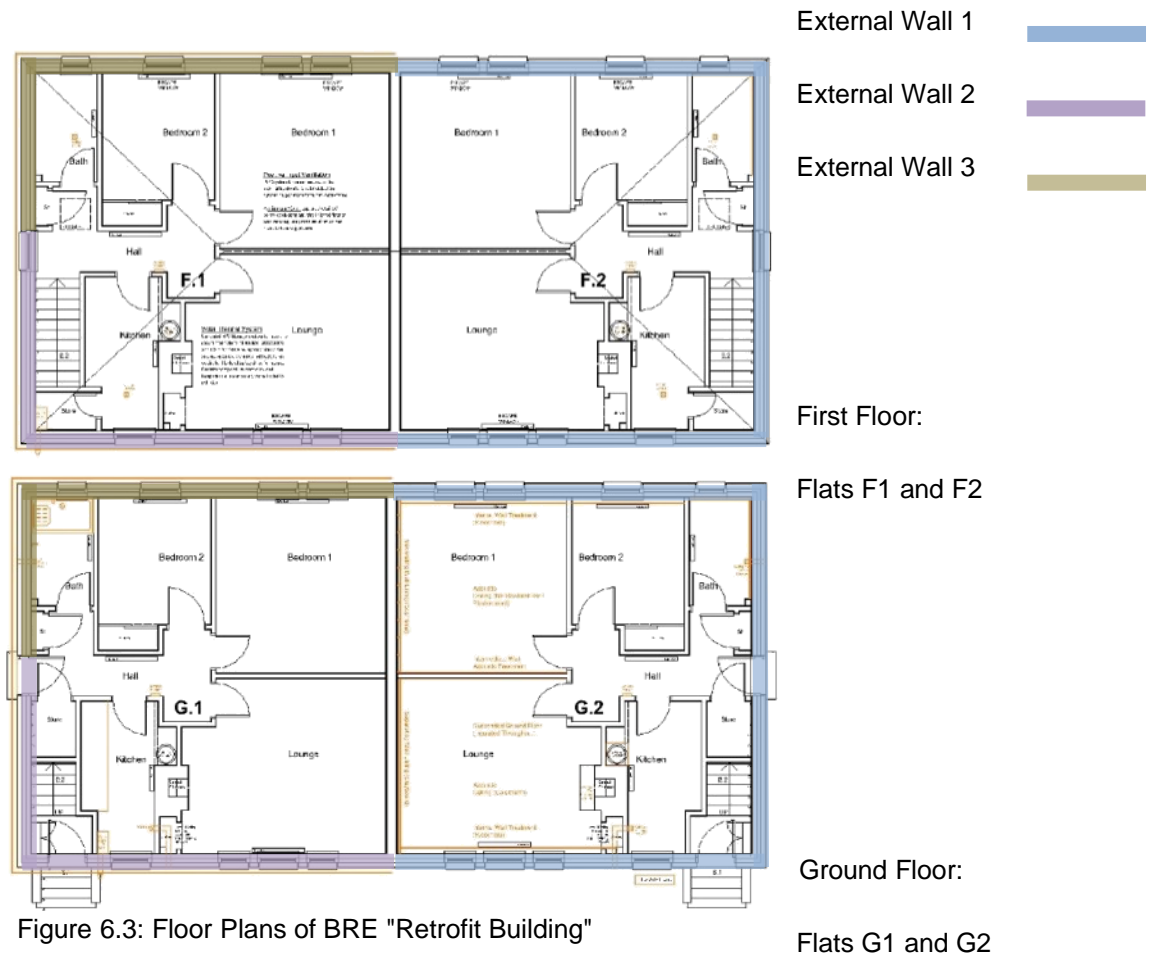
Figure 6.3: Floor Plans of BRE "Retrofit Building"

External finishes and insulation position are explained in the following table:

Table 6.11: BRE Ravenscraig Building external finishes

External Wall	Insulation	External finish
1	Internal	Lime & Render
2	External	
3		Brick Slip

181

The building addressed consists in a common load-bearing wall construction system made of brickwork walls and floors with timber I-joists and OSB panels. For this one building, there will be different scenarios assessed, depending on the external walls considered. These external cladding varies depending on the hypothesis evaluated for BRE as explained before. There will also be a scenario called "Zero" which would represent the building as it would have been built on the 60s or 70s, with no insulation at all.

6.4.1.1. Scenario 0: no insulation – basic construction

This scenario consists on the evaluating the basic building construction that it is assumed took place when first built. This is with no insulation at all within the building elements. External cladding is mortar render. Roof cladding is slate tiles.

6.4.1.2. Scenario 1: Brick work – internal polystyrene insulation – brick slips

In this scenario the building is renovated taking into account that houses are vacant hence internal work can be taken. This scenario involves the installation of thermal insulation on floors (between joists), external walls (internally) and roof (between trusses). The insulation is mineral fibre wool and thicknesses vary depending on the building element. External cladding is mortar render. Roof cladding is slate tiles.

6.4.1.3. Scenario 2: Brick work – external mineral insulation – Lime render

In this scenario the building is renovated taking into account that houses are not vacant hence internal work cannot be taken. In this case all renovation work are done externally, hence, this is from the outside. Insulation material is placed in same building elements using expanded polystyrene. Thicknesses vary depending on the building element. External cladding is brick slips. Roof cladding is clay tiles.

6.4.1.4. Scenario 3: concrete blocks – internal polystyrene insulation – brick slips

In this scenario the building is renovated under same circumstances as per scenario 2 but considering that internal walls and external leaves of external walls are made of prefabricated concrete blocks instead of bricks. Insulation material and thicknesses remain the same as previously. External cladding is brick slips. Roof cladding is clay tiles.

6.4.2. Physical description

- **Substructure: involves foundations and the ground floor**

6.4.2.1. Foundation

The foundations for this project consist of in-situ reinforced concrete (type of concrete and % of reinforcement) strips with dimensions 600m x 300mm. compacted gravel is placed. Then brickwork walls 500mm high are set up on the concrete strips alienated with the upper load-bearing walls of the building. Double brickwork is placed under external and party walls and single brickwork under internal walls.

Due to calculation purposes, the indicator unit should be "by unit of area". Since the strips and the gravel are placed linearly and segregated throughout all foundation area, an equivalent "slab" has been calculated for 150.92 sqm of area that foundation materials will be multiplied by within the tool in order to have the same cubic metre of concrete and gravel respectively.

In this case, strips are 0.6 x 0.4 m, with a total of 110 linear metre of strips. The total volume would be $26.4 m^3$. In order to have that same volume with a calculation area of $150.92 m^2$ we would need an equivalent slab 0.175m thick.

With gravel, with a thickness of 0.5m, in a total of $66 m^2$ we do the same calculations and an equivalent continuous surface of 0.303m is obtained.

For brick small walls calculation, same process has been considered but dividing the total impacts by the area of $150.92 m^2$, so the tool will have the total amount of impacts of all materials involved. Calculations shows a total of $55 m^2$ of single brick wall, and $37,95 m^2$ of double brick wall.

Table 6.12: Ravenscraig: concrete strips foundation layers (scenarios 0 & 1)

Layer	Material	Thickness	EE/m^2	EC/m2
(No)	(name)	(mm)	(MJ/m^2)	(KgCO$_2$e/m^2)
1	In-situ reinforced 20/25 concrete strips	175*[1]	716,15	74,03
2	Compacted Sand & Gravel	303*[1]	56,36	3,53
3	Single brick wall	102,5	161,99	13,86
4	Double brick wall	215	224,3	19,24
	Manufacturing Stage (A1-A3) Subtotal/m^2		**1158,8**	**110,66**

*[1] Average thickness of the equivalent element of 150,78 sqm, given the volume.

In-situ reinforced concrete raft 500x300mm:

This type of foundation consists on in-situ reinforced concrete slab 300mm thick with a thicker section of 500mm under the load-bearing walls lines. Then brickwork walls 500mm high are set up on the concrete strips alienated with the upper load-bearing walls of the building. Double brickwork is placed under external and party walls and single brickwork under internal walls.

In this case, the total volume of concrete would be 60.45m^3. To have that same volume with a calculation area of 150.92m^2 we would need an equivalent slab 0.400m thick.

Table 6.13: Ravenscraig: concrete raft foundation composition (scenarios 2 & 3)

Layer	Material	Thickness	EE/m^2	EC/m2
(No)	(name)	(mm)	(MJ/m^2)	(KgCO$_2$e/m^2)
1	In-situ concrete 20/25 raft foudation	400*1	1.639,82	169,51
2	Dump membrane	3	450,24	4,03
3	Single brick wall	102,5	161,99	13,86
4	Double brick wall	215	224,3	19,24
	Manufacturing Stage (A1-A3) Subtotal/m^2		2.476,35	206,64

*[1] Average thickness of the equivalent element of 150,78 sqm, given the volume.

6.4.2.2. Ground floor

The ground floor consists of I-joists 225mm high @ 400mm over the brickwork walls. Mineral fibre insulation 200mm thick is placed between the joists with OSB 12mm thick is placed over the joists and then finished with general carpet.

Table 6.14: Ravenscraig: ground floor composition

Layer	Material	Thickness	EE/m^2	EC/m2
(No)	(name)	(mm)	(MJ/m^2)	(KgCO$_2$e/m^2)
1	General Carpet	22	9,80	187,00
2	Timber particle board	22	281,60	19,18
3	Softwood battens 50x50mm	0,05	21,25	1,53
4	Timber particle board	22	281,60	19,18
5	Timber I-joist @ 400mm (2,5 joists per m2)	45*[2]	6,01	88,81
6-Sc1	Mineral wool insulation	150	261,45	20,16
6-Sc2&3	Expanded polystyrene insulation	150	598,05	22,21
		Scenario 0	600,26	315,70
	Manufacturing Stage (A1-A3) Subtotal/m^2	Scenario 1	861,71	335,86
		Scenarios 2 & 3	1.198,31	337,91

*[2] Calculation in detail in APPENDIX A

- **Superstructure: all other elements above ground**

The superstructure of the building involves all parts above the foundations such as walls and floors, roof, including external cladding and internal finishes.

6.4.2.3. Upper floors

Upper floor is made with timber I-joists, same as per the ground floor, over the load-bearing walls situated along the short side of the building (L=8m). It has 22mm OSB panels over the joists and it's finished with general carpet. The ceiling below the joists is made of 9mm plasterboard fixed to light metal studs (50mm), which are fixed to the joists, and finished with two coats of general paint.

Table 6.15: Ravenscraig: upper floor composition

Layer	Material	Thickness	EE/m^2	EC/m2
(No)	(name)	(mm)	(MJ/m^2)	(KgCO$_2$e/m^2)
1	General Carpet	22	9,80	187,00
2	Timber particle board	22	281,60	19,18
3	Softwood battens 50x50mm	55	21,25	1,53
4	Timber particle board	22	281,60	19,18
5	Timber I-joist @ 400mm (2,5 joists per m2)	45[2]	6,01	88,81
6	Light metal studs @600mm	50	6,36	0,54
7	Plasterboard	125	75,94	4,38
8	General paint (two coats)	0,1	21,02	0,87
	Manufacturing Stage (A1-A3) Subtotal/m^2		**703,58**	**321,49**

[2] Calculation in detail in APPENDIX A

6.4.2.4. Roof

The roof is built with triangular timber trusses of different sections. The inclination is 30 degrees and the external cladding is slate tiles. Mineral Fibre insulation 150mm thick is placed between the bottom chords when scenario 1 is assessed and same thickness of expanded polystyrene when scenarios 2 and 3 are evaluated. All options are displayed in one only table, as follows:

Table 6.16: Ravenscraig: roof composition

Layer	Material	Thickness	EE/m^2	EC/m2
(No)	(name)	(mm)	(MJ/m^2)	(KgCO$_2$e/m^2)
1-Sc0&1	Slates slips for roof	12	8,40	157,08
1-Sc2&3	Ceramic tiles	12	148,20	10,95
2	Dump membrane	5	450,24	4,03
3	Timber particle board	22	281,60	19,18
4	Timber truss @600mm (30º)	100 *^{2}	621,60	42,53
5-Sc1	Mineral wool insulation	150	261,45	20,16
5-Sc2&3	Expanded polystyrene insulation	150	598,05	22,21
6	Plasterboard	125	75,94	4,38
7	General paint (two coats)	0,1	21,02	0,87
		Scenario 0	**1.458,80**	**228,07**
	Manufacturing Stage (A1-A3) Subtotal/m^2	**Scenario 1**	**1.720,25**	**248,23**
		Scenarios 2 & 3	**2.196,65**	**104,15**

*^{2} Calculation in detail in APPENDIX A

6.4.2.5. External walls

External walls consist in 2 leaves with an air gap (cavity) between them, external cladding and internal finish. Both leaves are made of single load-bearing brick wall except for the scenario 3 in which is made of concrete blocks. External cladding varies depending on the scenario assessed having two options: mortar lime & render and brick slips. Internally, plasterboard is fixed to the wall with cement dots and tab and finished with general paint. All options are summarised as follows:

Table 6.17: Ravenscraig building external finishes

Scenario	Internal leaf	External leaf	Insulation	External finish
BRE-0	Single brick wall	Single brick wall	-	Lime & Render
BRE-1			Internal (MW)	
BRE-2			External (EP)	Brick Slip
BRE-3		Concrete		

First scenario studied is the current status of lots of homes within the UK. This involves no insulation at all, all walls made of brick work, with an external finish of painted mortar render.

Scenario 1 would be the first retrofit option evaluated and, as explained before, it would be happening having vacant the building, so that, empty of users. If this is the case retrofit works will be carried out from the inside. Hence, mineral wool insulation between light metal studs is incorporated, maintaining all finishes internal and externals:

Table 6.18: Ravenscraig: external wall Scenarios 0 &1 composition

Layer (No)	Material (name)	Thickness (mm)	EE/m^2 (MJ/m^2)	EC/m2 (KgCO$_2$e/m^2)
1	General paint (two coats)	0,1	21,02	0,87
2	General cement plaster	10	25,20	1,82
3	UK Single brick wall	102,5	444,51	38,03
4	Air gap	80	0,00	0,00
5	UK Single brick wall	102,5	444,51	38,03
6-Sc1	Mineral wool insulation	100	174,30	13,44
7-Sc0	Dot and Dab cement	10	2,97	0,48
7-Sc1	Light metal studs @600mm	50	29,75	2,14
8	Plasterboard	12,5	75,94	4,39
9	General paint (two coats)	0,1	21,02	0,87
Manufacturing Stage (A1-A3) Subtotal/m^2		Scenario 0	1.035,17	84,49
		Scenario 1	1.236,25	99,59

Then a second retrofit option is studied thinking on a possible renovation having families living inside. Hence, external insulation is adopted on external walls and external finish changed to brick slips attached with mortar.

For this external retrofit option a new version is compared as if all external leaves were made with concrete blocks, keeping finishes and same insulation. That would result on scenario 3.

Table 6.19: Ravenscraig: external wall Scenarios 2&3 composition

Layer	Material	Thickness	EE/m^2	EC/m2
(No)	(name)	(mm)	(MJ/m^2)	(KgCO$_2$e/m^2)
1	Brick Slips	13	55,59	4,44
2	Cement mortar	5	12,60	0,91
3	Expanded polystyrene insulation	100	398,70	14,81
4	UK Single brick wall	102,5	444,51	38,03
5	Air gap	80	0,00	0,00
6-Sc2	UK Single brick wall	102,5	444,51	38,03
6-Sc3	Concrete block (d=10cm)	100	148,54	20,27
7	Dot and Dab cement	10	2,97	0,48
8	Plasterboard	12,5	75,94	4,39
9	General paint (two coats)	0,1	21,02	0,87
Manufacturing Stage (A1-A3) Subtotal/m^2		Scenario 2	1.455,84	101,96
		Scenario 3	1.159,87	84,20

6.4.2.6. Internal walls

Internal walls are made of a single load-bearing brickwork wall 102.5 mm thick. Plasterboards are fixed with dot and tab system to both sides and finished with 2 coats of general paint.

Table 6.20: Ravenscraig: internal wall composition

Layer (No)	Material (name)	Thickness (mm)	EE/m^2 (MJ/m^2)	EC/m2 (KgCO$_2$e/m^2)
1	General paint (two coats)	0,1	21,02	0,87
2	Plasterboard	12,5	75,94	4,39
3	Dot and Dab cement	10	2,97	0,48
4-Sc0&1	UK Single brick wall	102,5	444,51	38,03
4-Sc2&3	Concrete block (d=10cm)	100	148,54	20,27
5	Dot and Dab cement	10	2,97	0,48
6	Plasterboard	12,5	75,94	4,39
7	General paint (two coats)	0,1	21,02	0,87
Manufacturing Stage (A1-A3) Subtotal/m^2		Scenario 0&1	**644,37**	**49,51**
		Scenario 2&3	**348,40**	**31,75**

6.4.2.7. Party walls

Party walls are defined exactly as the internal walls with the only difference of the double brick wall instead of the single one.

Table 6.21: Ravenscraig: party wall composition

Layer (No)	Material (name)	Thickness (mm)	EE/m^2 (MJ/m^2)	EC/m2 (KgCO$_2$e/m^2)
1	General paint (two coats)	0,1	21,02	0,87
2	Plasterboard	12,5	75,94	4,39
3	Dot and Dab cement	10	2,97	0,48
4-Sc0&1	UK double brick wall	215	891,99	76,53
4-Sc2&3	Concrete dense block	200	564,72	332,28
5	Dot and Dab cement	10	2,97	0,48
6	Plasterboard	12,5	75,94	4,39
7	General paint (two coats)	0,1	21,02	0,87
Manufacturing Stage (A1-A3) Subtotal/m^2		Scenario 0&1	**1.091,85**	**88,01**
		Scenario 2&3	**764,58**	**343,76**

6.4.2.8. Windows

External windows change with scenarios studied. For scenario 0, which is the baseline option, they are defined as timber frame windows with single glazed. For scenarios 1 & 2 they are considered as timber framed double glazed. For the last scenario studied a PVC frame with double glazed is considered.

There are 34 windows within this project, with a total glazed area of 45.18 m2. For calculation purposes, glazed area is considered instead of the number of windows, as explain on "APPENDIX A – VI".

Table 6.22: Ravenscraig: windows options

Scenario	Material	Glazed	EE/m^2	EC/m^2
(No.)	(name)	(type)	(MJ/m^2)	(KgCO$_2$e/m^2)
0	Timber framed	Single	159.72	8.33
1 & 2	Timber framed	Double	340.28	17.36
3	PVC framed	Double	1715.28	87.50

6.4.2.9. Doors

a) External doors

External doors are security and fire doors. For calculation purposes are calculated as PVC framed doors.

b) Internal doors

Internal doors are specified as timber framed doors, with dimensions 80 by 210cm. The doors are made by a 5cm timber battens and laminated veneer in both sides.

Table 6.23: Ravenscraig doors impacts

Element	Material	Type	EE/m^2	EC/m^2
(No.)	(name)		(MJ/m^2)	(KgCO$_2$e/m^2)
1	External door	Fire protection	117.03	9.71
2	Internal door	Timber framed	47.57	3.79

- **Internal finishes**

6.4.2.10. Internal finishes

Internal finishes involve the following construction elements:

a) Internal Walls or internal leaf of external walls. They are always assumed as one plasterboard finished with two coats of general paint

b) Ceilings are assumed to finish with plasterboard and two coats of general paint.

c) Floors finishes are assumed to be general carpets in all rooms for simplicity within the tool. Should specific floor finishes for each room were the case, future work on the tool would be needed.

These internal finishes specification have been also included in their correspondent construction element previously defined for coherence when reading this section. However, they are defined separately within the user-friendly tool for simplicity when approaching the LCA process. All the internal finishes used within the Ravenscraig scenarios are summarised below, with no subtotal row.

Table 6.24: Ravenscraig: finishes options used for simulation

Finishes	Material	Thickness	EE/m^2	EC/m^2
	(name)	(mm)	(MJ/m^2)	(KgCO$_2$e/m^2)
Wall, floor and ceiling	Plasterboard	12,5	75,94	4,38
	General paint (two coats)	0,1	21,02	0,87
	General Carpet	22	9,80	187,00

6.4.3.   Material selection by scenario

Table 6.25: material options for BRE case study

Building element		Scenario 0	Scenario 1	Scenario 2	Scenario 3
Foundation	Material	Concrete Strip 600x400mm + compacted gravel 500mm		Concrete Raft 500/300mm	
	Insulation	-		-	
Ground Floor	Material	Timber I-Joists @400mm. OSB + General Carpet			
	Insulation	No insulation	Mineral Fibre 100mm	Expanded polystyrene 100mm	
Upper Floor	Material	Timber I-Joists @400mm. OSB + General Carpet			
	Insulation	No insulation	Mineral Fibre 100mm	Externally: expanded polystyrene 100mm	
External Wall	Int. Leaf	Single Brick work - 102.5mm			
	Ext. Leaf	Single Brick work - 102.5mm			Single concrete block - 100mm
	Insulation	No Insulation	Internally: mineral Fibre 100mm	Externally: expanded polystyrene 100mm	
Internal Walls		Single Brick work - 102.5mm			Single concrete block - 100mm
Party Wall		Double Brick work - 215mm			Double Concrete Block - 200mm
Roof	Materials	Timber Truss @400mm + Slate tiles		Timber Truss @400mm + Ceramic tiles	
	Insulation	No Insulation	Mineral Fibre 150mm	Between trusses: expanded polystyrene 150mm	
External windows		Timber Framed single glazed	Timber framed double glazed	Timber framed double glazed	PVC Framed single glazed
External doors		Timber framed			
Internal doors		Timber framed			
Internal Finishes		Plasterboard + general paint 2 coats			
External Finish		Lime Render + general paint		Brick slips	

6.4.4. Results

As a summary of all scenarios assessed, the previous table indicates all material assumptions taken into consideration within the evaluations. Results will be showed by scenario.

Global results show that embodied carbon and energy follow same pattern, but energy figures for all LCA stages are nearly 10 times bigger than figures for carbon.

Even though either energy or carbon are equally important as impact indicators of this process, this thesis will be focusing on the embodied carbon emission calculations, as indicated previously, since they are the emissions referred to materials.

Scenario 0: NO INSULATION

Results show the following impacts by LCA stage for both indicators, having most of them due to the operational phase (B6). This is a repeated pattern within all scenarios, as it was expected.
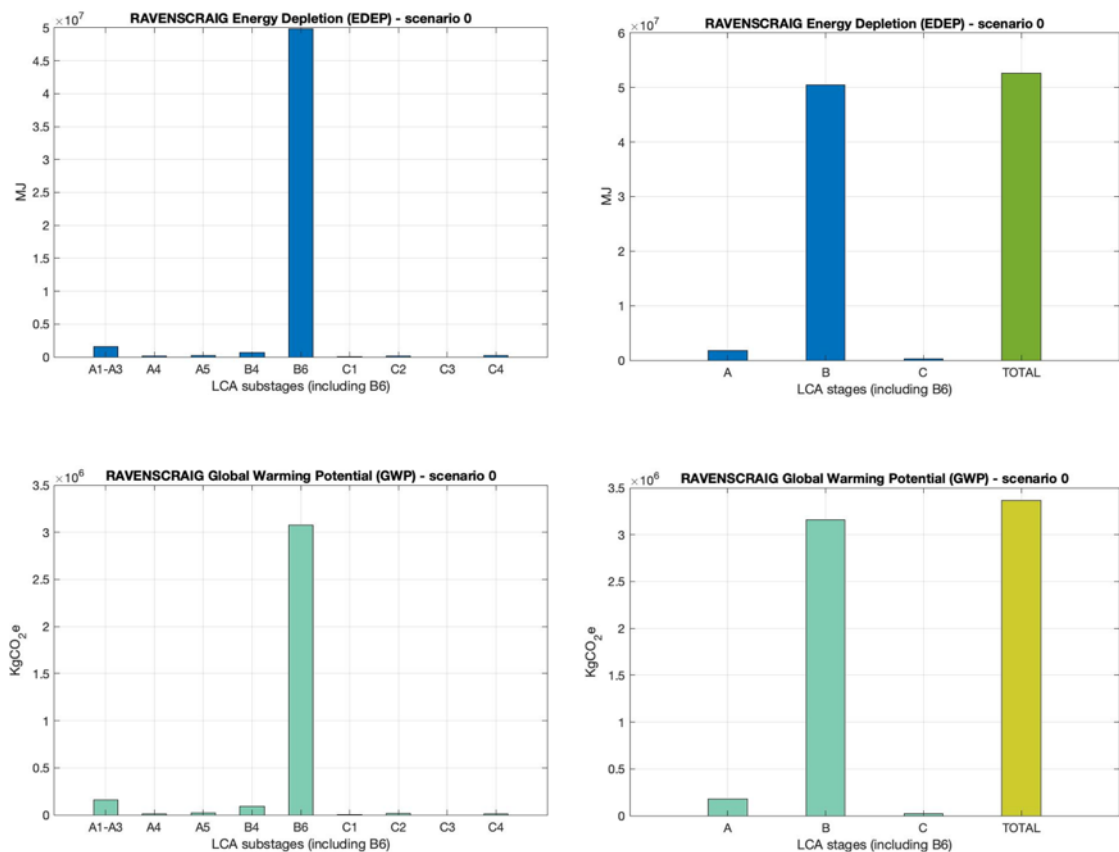
Figure 6.4: Retrofit Building Scenario 0. Bar plots with results by LCA stages.
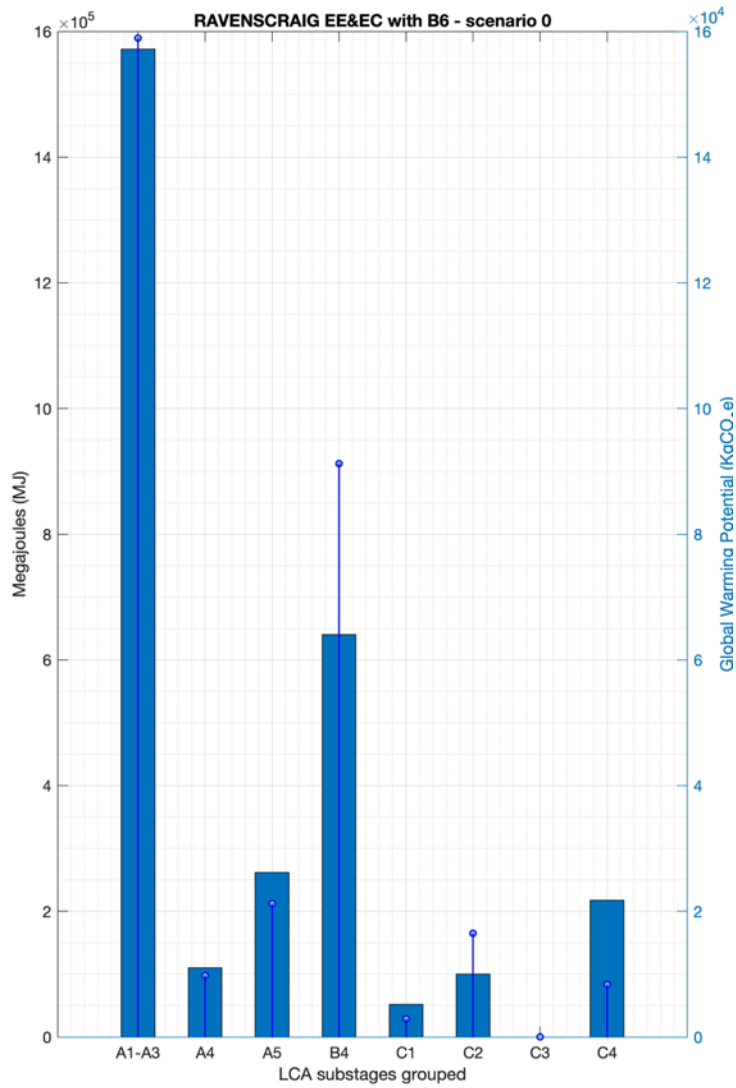
Figure 6.5: Retrofit Building scenario 0. Combo bar plot with results of embodied energy & carbon

Regarding the carbon impacts, we can see the following percentages by LCA stage:
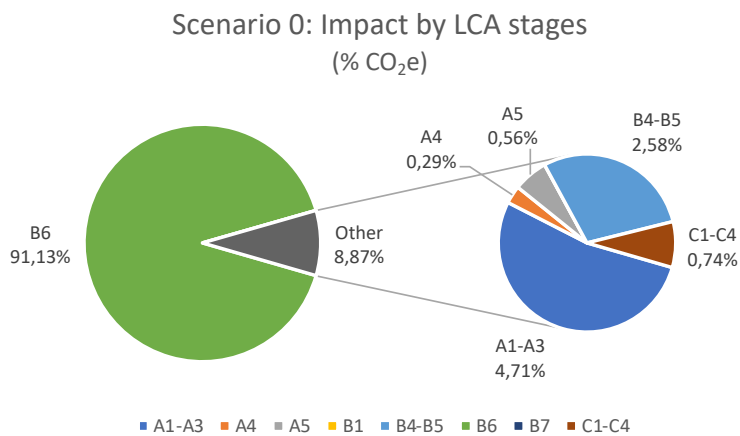
Figure 6.6: Retrofit Building scenario 0. Pie chart with percentage of results by LCA stages

Table 6.26: Retrofit Building scenario 0. Summary of carbon results by LCA stages

Results by stages - RAVENSCRAIG		SCENARIO 0	
LCA Stages		TonCO$_2$e	Fraction %
A1-A3	Manufacturing	158,94	4,71%
A4	Transport to site	8,17	0,24%
A5	Construction	18,79	0,56%
B1	Use	0,00	0,00%
B4-B5	Replacements and renovations	87,02	2,58%
B6	Energy use	3.074,75	91,17%
B7	Water use	0,00	0,00%
C1-C4	End-of-life	24,87	0,74%
Subtotal		3.372,55	100,00%

Results for manufacturing impact by building element would be the following:
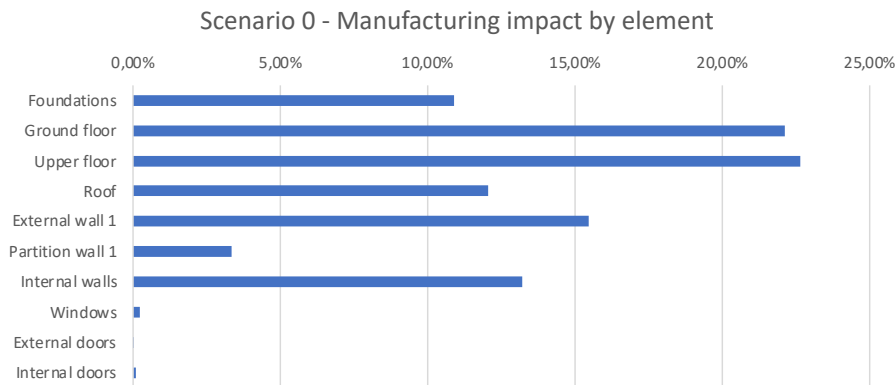
Figure 6.7: Retrofit Building_Scenario 0. Bar results with A1-A3 stages impacts

As it is seen, upper floor has the greatest manufacturing impact, followed by the ground floor. On the other hand, doors and windows have the smallest impact in terms of singular elements.

Regarding the embodied carbon, this scenario obtains, within the life cycle of the building, a result of 921,33 KgCO$_2$e/m^2 (SIB).

Scenario 1: Internal Mineral Wool insulation

Results show the following impacts by LCA stage for both indicators, having most of them due to the operational phase (B6).
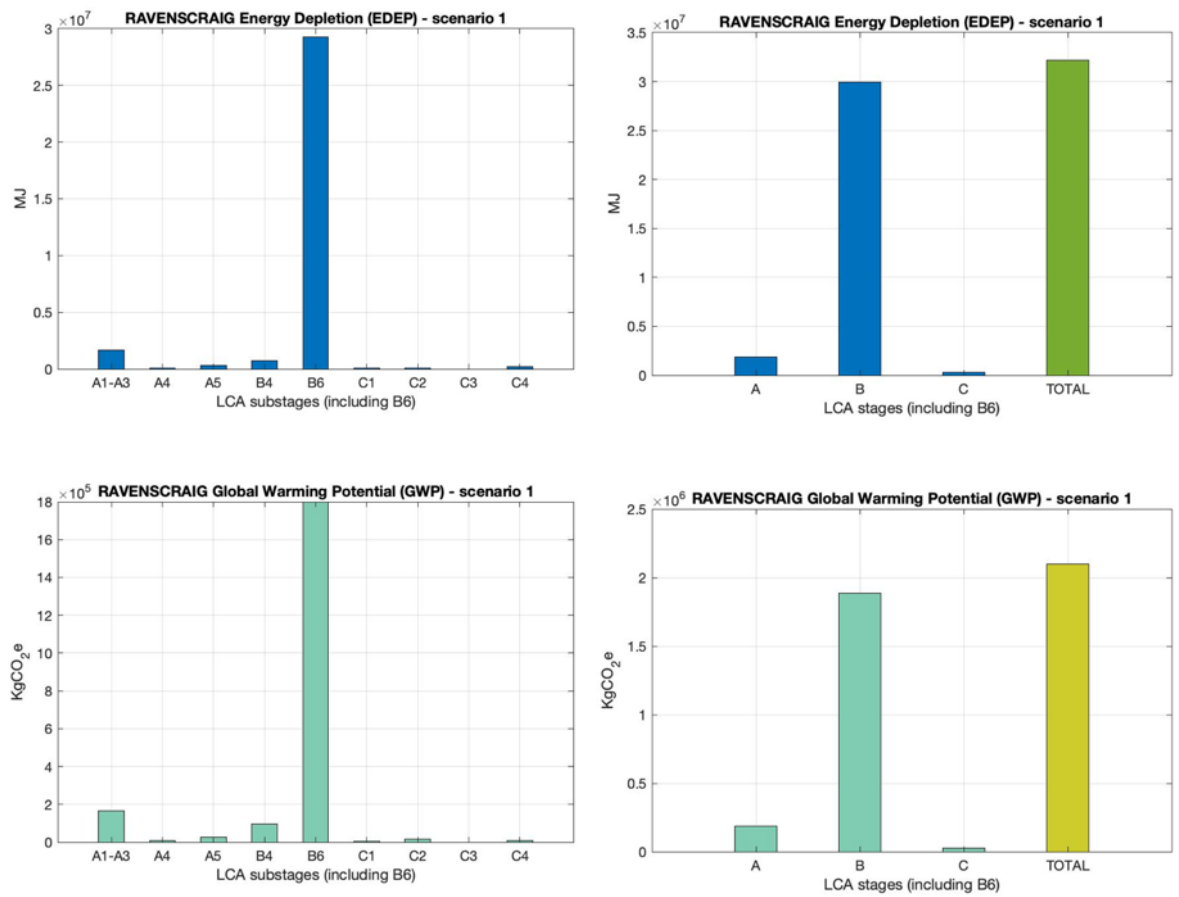
Figure 6.8: Retrofit building scenario 1. Bar plots with results by LCA stages
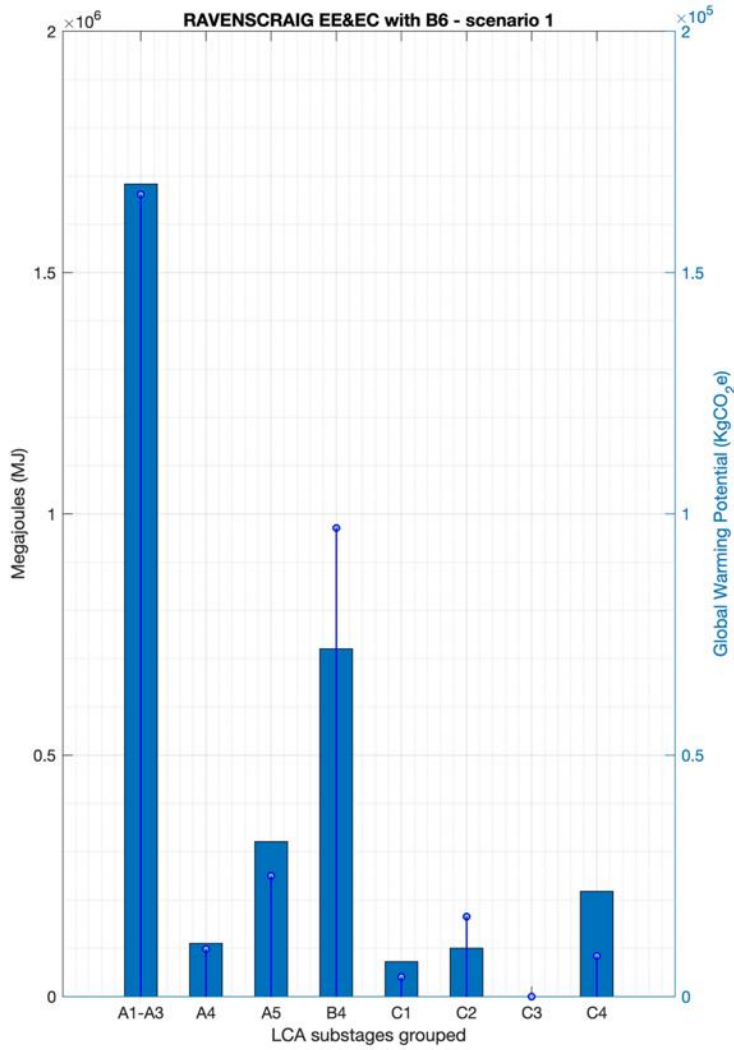
Figure 6.9: Retrofit Building scenario 1. Combo bar plot with results of embodied energy & carbon

Regarding the carbon impacts, we can see the following percentages by LCA stage:
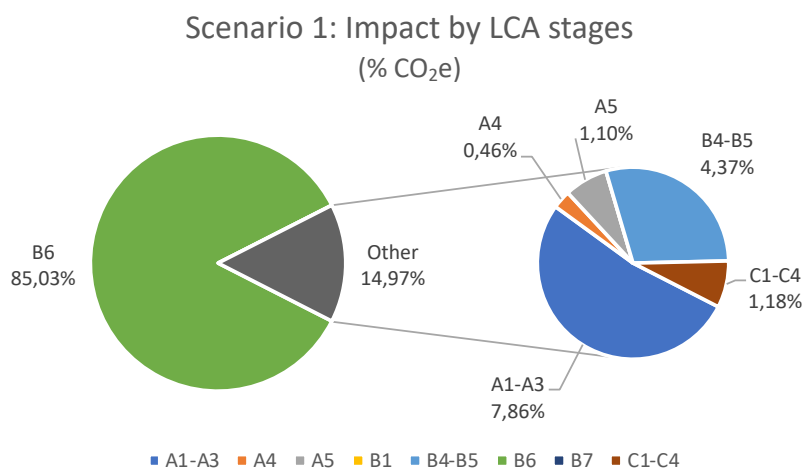
Figure 6.10: Retrofit Building scenario 1. Pie chart with percentage of results by LCA stages

Table 6.27: Retrofit Building scenario 1. Summary of carbon results by LCA stages

Results by stages - RAVENSCRAIG		SCENARIO 1	
LCA Stages		TonCO$_2$e	Fraction %
A1-A3	Manufacturing	166,22	7,86%
A4	Transport to site	9,82	0,46%
A5	Construction	23,23	1,10%
B1	Use	0,00	0,00%
B4-B5	Replacements and renovations	92,34	4,37%
B6	Energy use	1.797,38	85,03%
B7	Water use	0,00	0,00%
C1-C4	End-of-life	24,92	1,18%
Subtotal		**2.113,91**	**100,00%**

Results for manufacturing impact by building element would be the following:
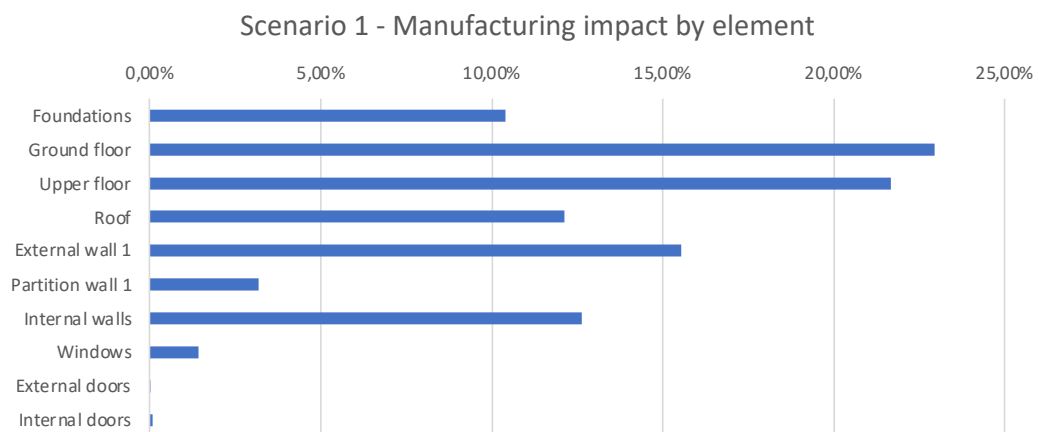
Figure 6.11: Retrofit Building scenario 1. Bar results with A1-A3 stages impacts

As it is seen, ground floor has the greatest impact, followed by the upper floor. On the other hand, doors and windows would have the smallest impact in terms of singular elements.

Regarding the embodied carbon, this scenario obtains, within the life cycle of the building, a result of 973,93 KgCO$_2$e/m^2 (SIB).

Scenario 2: External Expanded Polystyrene insulation – brick work walls

Results show the following impacts by LCA stage for both indicators, having most of them due to the operational phase (B6).
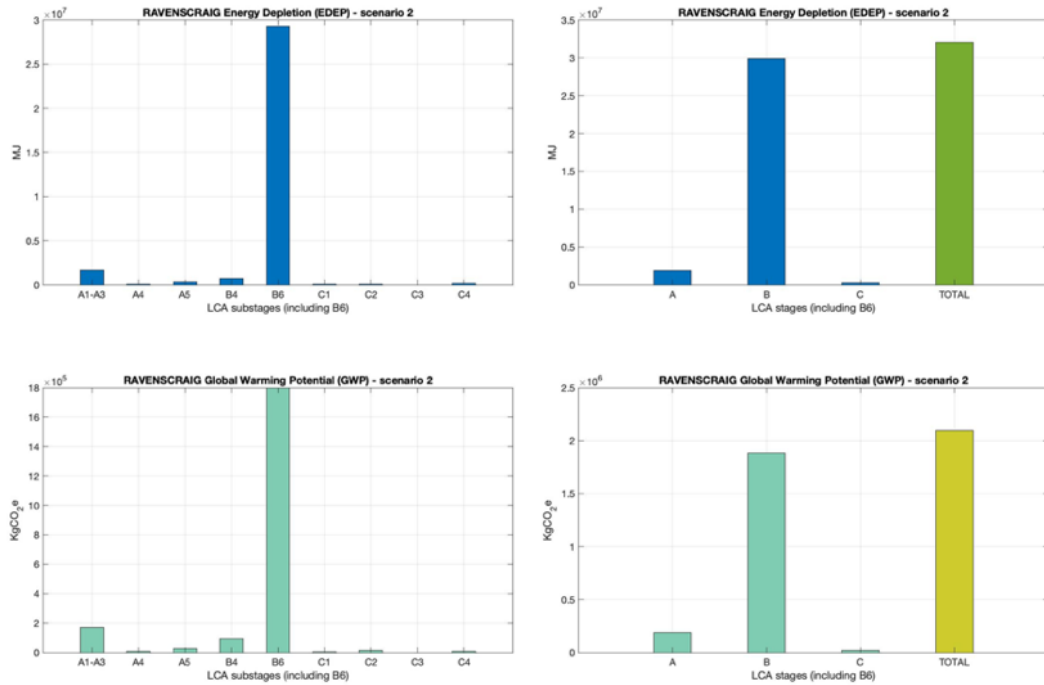
Figure 6.12: Retrofit Building scenario 2. Bar plots with results by LCA stages
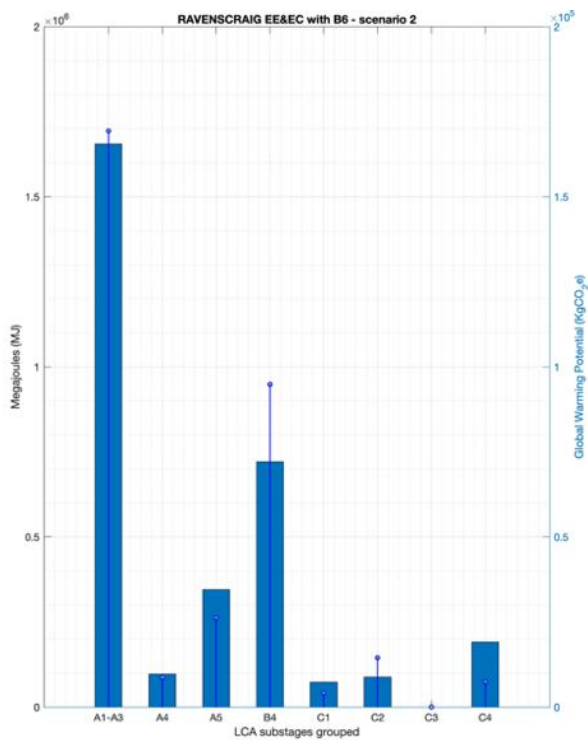
Figure 6.13: Retrofit Building scenario 2. Combo bar plot with embodied energy & carbon

Regarding the carbon impacts, we can see the following percentages by LCA stage:
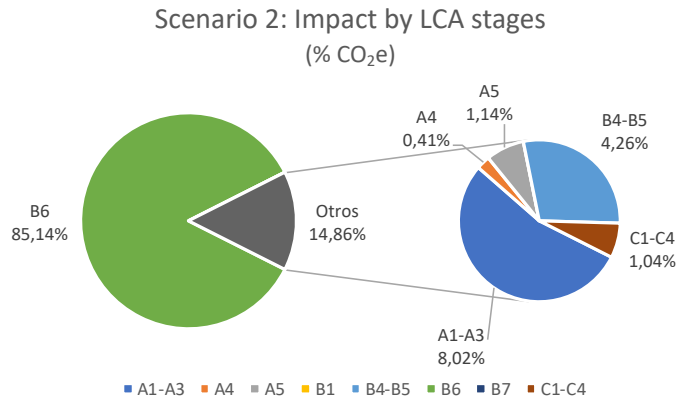
Figure 6.14: Retrofit Building scenario 2. Pie chart with percentage of results by LCA stages

Table 6.28: Retrofit Building scenario 2. Summary of carbon results by LCA stages

Results by stages - RAVENSCRAIG		SCENARIO 2	
LCA Stages		TonCO$_2$e	Fraction %
A1-A3	Manufacturing	169,36	8,02%
A4	Transport to site	8,61	0,41%
A5	Construction	24,01	1,14%
B1	Use	0,00	0,00%
B4-B5	Replacements and renovations	89,83	4,26%
B6	Energy use	1.797,38	85,14%
B7	Water use	0,00	0,00%
C1-C4	End-of-life	21,86	1,04%
Subtotal		**2.111,06**	**100,00%**

Results for manufacturing impact by building element would be the following:
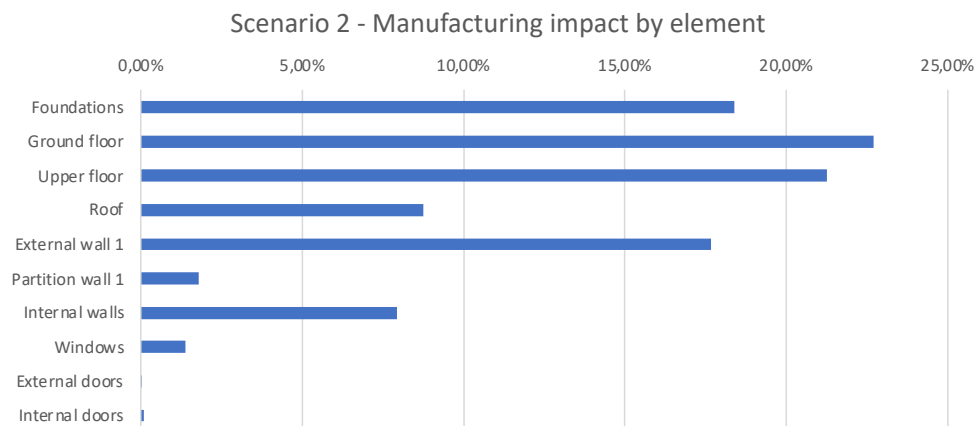
Figure 6.15: Retrofit Building scenario 2. Bar results with A1-A3 stages impacts

As it is seen, ground floor has the greater impact, followed by the upper floor, foundations and external walls. On the other hand, doors and windows would have the smallest impact in terms of singular elements.

Regarding the embodied carbon, this scenario obtains, within the life cycle of the building, a result of 965,17 KgCO$_2$e/m^2 (SIB).

Scenario 3: External Expanded Polystyrene insulation – concrete blocks walls

Results show the following impacts by LCA stage for both indicators, having most of them due to the operational phase (B6).
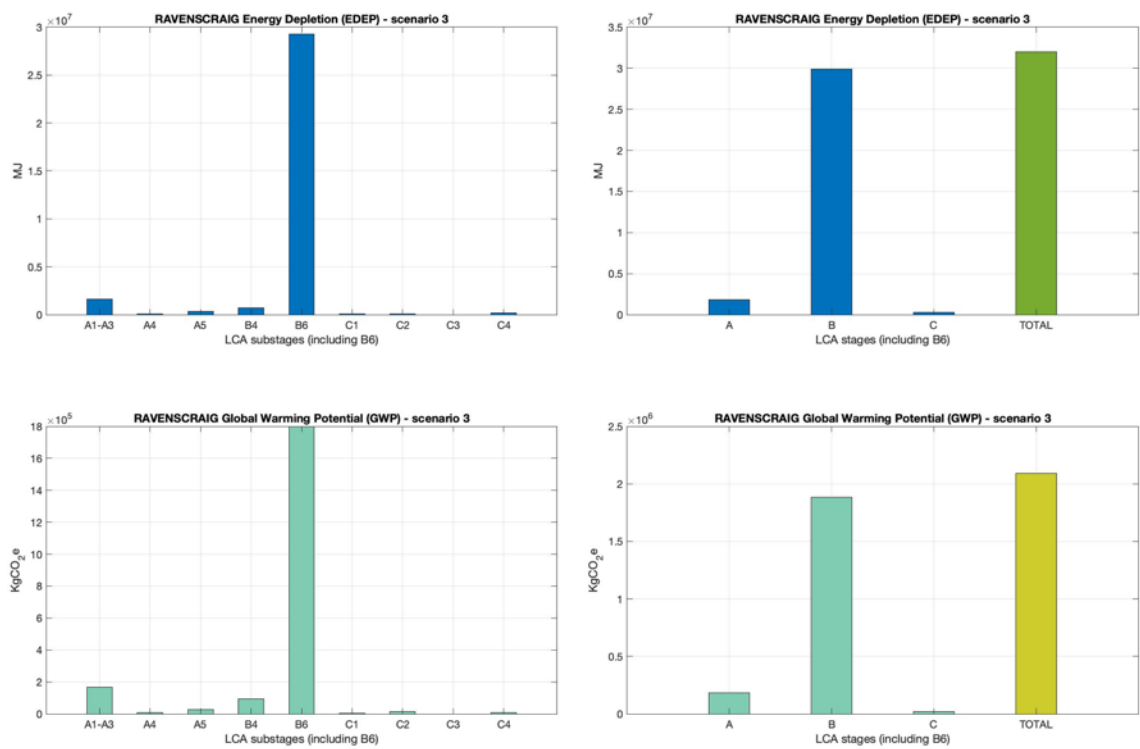
Figure 6.16: Retrofit Building Scenario 3. Bar plots with results by LCA stages
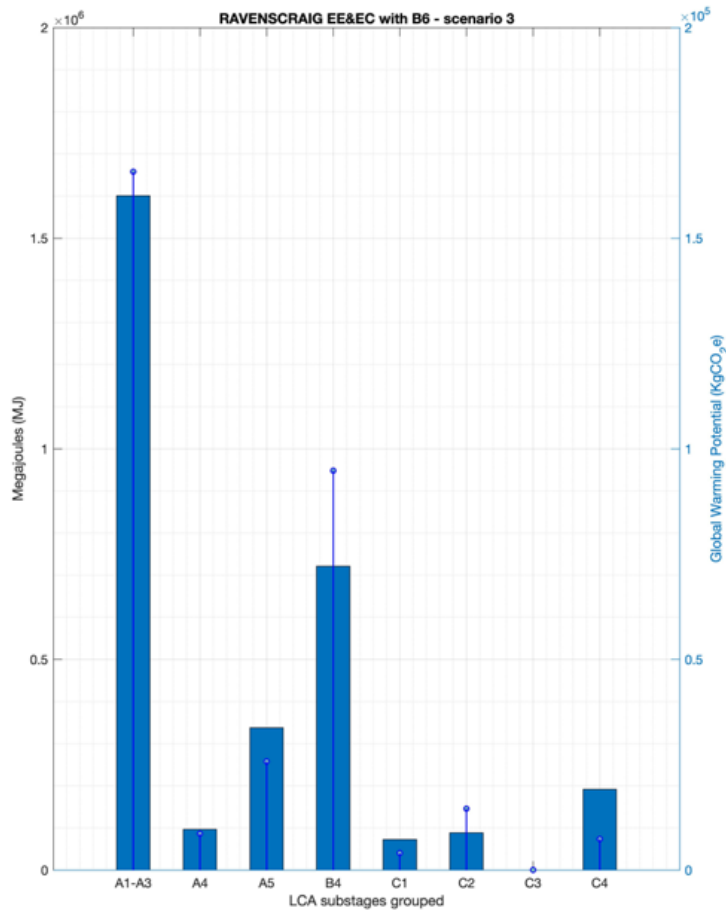
Figure 6.17: Retrofit Building scenario 3. Combo bar plot with results of embodied energy & carbon

Regarding the carbon impacts, we can see the following percentages by LCA stage:
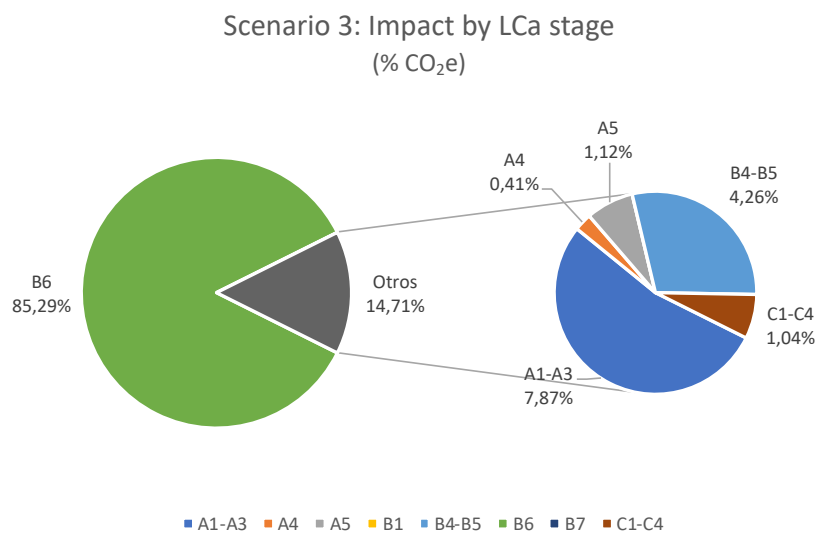
Figure 6.18: Retrofit Building scenario 3. Pie chart with percentage of results by LCA stages

Table 6.29: Retrofit Building_Scenario 3. Summary of carbon results by LCA stages

Results by stages - RAVENSCRAIG		SCENARIO 3	
LCA Stages		TonCO$_2$e	Fraction %
A1-A3	Manufacturing	165,80	7,87%
A4	Transport to site	8,65	0,41%
A5	Construction	23,65	1,12%
B1	Use	0,00	0,00%
B4-B5	Replacements and renovations	89,84	4,26%
B6	Energy use	1.797,38	85,29%
B7	Water use	0,00	0,00%
C1-C4	End-of-life	21,94	1,04%
Subtotal		**2.107,25**	**100,00%**

Results for manufacturing impact by building element would be the following:

Scenario 3 - Manufacturing impact by element
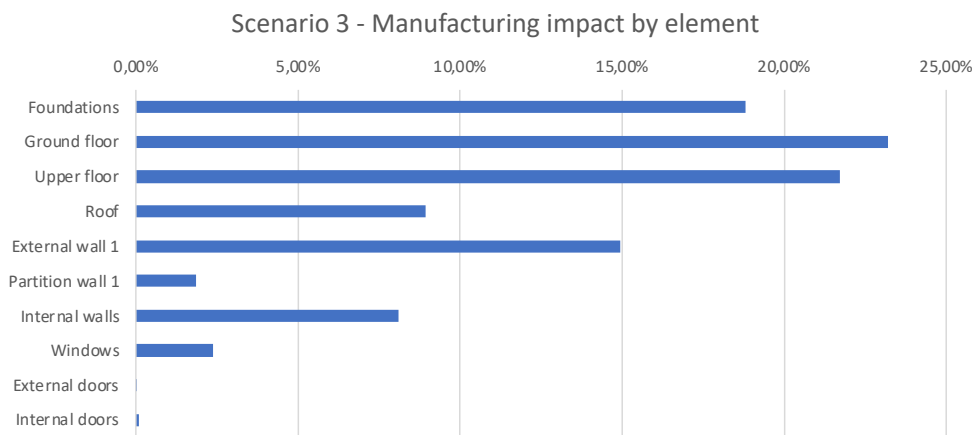
Figure 6.19: Retrofit Building_Scenario 3. Bar results with A1-A3 stages impacts

As it is seen, ground floor has the greater impact, followed by the upper floor and foundations. On the other hand, doors and windows would have the smallest impact in terms of singular elements.

Regarding the embodied carbon, this scenario obtains, within the life cycle of the building, a result of 953,47 KgCO$_2$e/m^2 (SIB).

Comparison between all different scenarios that have been evaluated for this case study would be the following, by LCA stage:
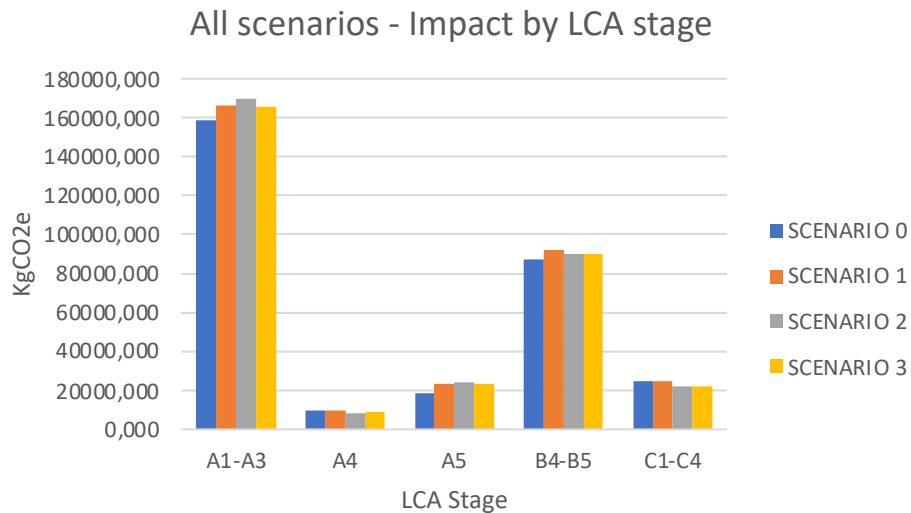
Figure 6.20: Retrofit building – carbon results comparison between all scenarios

From this first comparison, it is noticed that the manufacturing stage shows how the more material is installed, the more impacts it has. This is obvious since more material is being added to the building. However, it is seen that depending on how the combination of materials is used within the building elements, impacts not always should raise, but they could be lower, such as in scenario 3. In that scenario more concrete block is used, instead of brick work walls as well as polystyrene insulation instead of mineral wool.

However, it is noticed that the transport and end-of-life impacts decrease due to more circularity of materials of scenarios 2 and 3, using more concrete block instead of brick works.

Stage A5 increases gradually with more materials installed, as it was expected but replacements for the last two scenarios is slightly smaller than for the scenario 1 due to the longer life service of the insulation type used for these cases and finishes of external wall and roof.

At the end-of-life stage, it is seen that, again, that last two scenarios would have less impacts for the circularity of the materials commented previously.

A deeper results indication, with more comparisons between materials and elements, will be commented on the following chapter 7: sensitivity analysis.

6.5.   CLT Building (CLTB)

6.5.1. Building description

This building, core of the assessment for this third case study, consists of 42 flats development using cross laminated timber as main support structure for walls and floors. It is located at Ellerside Road at Yoker, Glasgow, UK, built by CCG.

This project involves a 8 storeys building with the particularity of the structure frame made of CLT off-site manufactured solid walls. This is the first building built in Scotland with this innovative system. Its construction started in December 2016 and has been finished in September 2017.

The building process has been followed with several site visits and this research has also been part of a wider research group leaded for Napier University and Construction Scotland Innovation Centre.
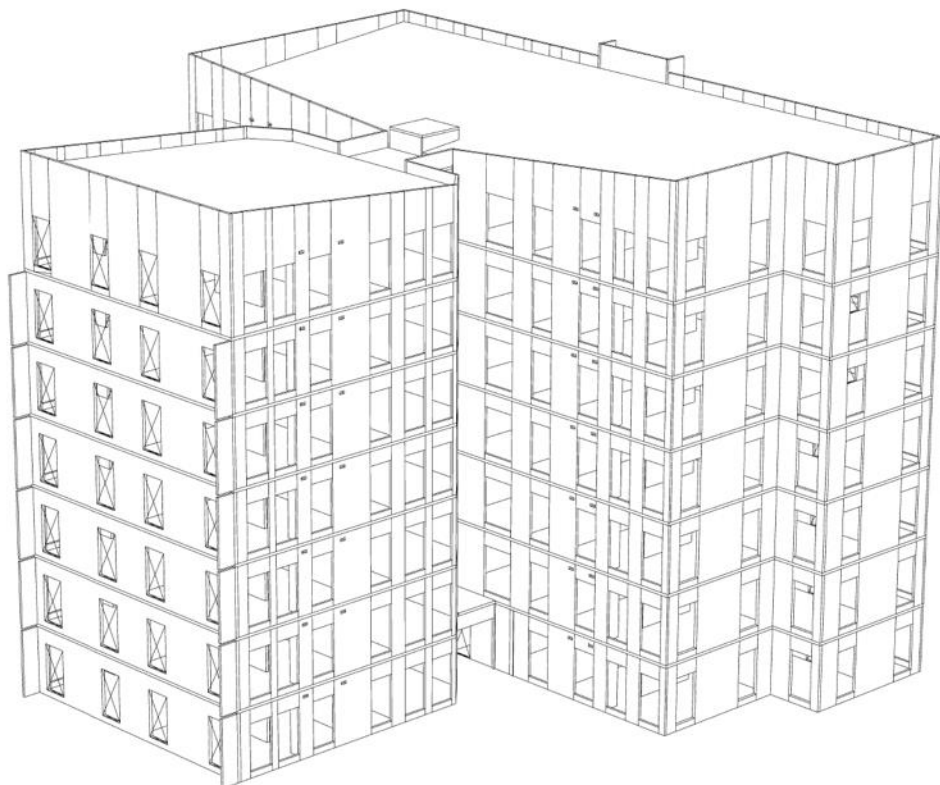
Figure 6.21: CCG Yoker project axonometry

The CLT timber used offers a sustainable alternative to Steel or concrete enhancing the environmental efficiency of the hole building. The construction process differs from the conventional as all structure is previously manufactured off-site.

Concrete slabs foundations are the base for this CLT structure which will arise 7 storeys from the ground having a footprint next to 550sqm. Both, floors and walls are CLT off-site manufactured and assembled on-site with incredible accuracy and speed.

External finish is lightweight cladding using acrylic brick slips and metal sheets offering a stunning combination for all facades.

Internally, the building has been finished with insulated light metal studs for painted plasterboards.

Insulation will be an important material for this construction having into account the very small airtightness accomplished.

Figure 6.22: Yoker intermediate floor plan by wall type

6.5.2. Physical description

This building consists on 8 storeys building with the particularity of the structure frame made of CLT off-site manufactured solid walls. This is the first building built in Scotland with this innovative system. Its construction started in December 2016 and has been finished in September 2017.

- **Substructure: foundation and ground floor**

6.5.2.1. Foundation

The foundations for this project consist on a reinforced concrete (20/25 with 6% of steel reinforcement) strips with dimensions that varies from 60x60cm to 60x100cm poured over 144 concrete piles of dimensions within the range of R150mm by 30m to R150mm by 15m. Compacted gravel and polystyrene rigid insulation 150mm thick is been placed between strips. A layer of dump membrane, 3mm thick, is been situated below the foundations.

In this case, footprint area is 550sqm, which is the area that will be multiply by within the tool. So that for complex elements, such as piles or concrete strips of different sections, to be measured by area, a "flat" equivalent element should be addressed in order to operate with it and achieve indicators by sqm.

a) Concrete piles calculation:

An equivalent concrete slab is been calculated for 550sqm of area that foundation will be multiplied by in order to have the same cubic metre of concrete used for piles. The equivalent continuous layer would be as a 277mm concrete slab.

There is a total of 144 piles of R150mm and 15 to 30m deep. Total volume of concrete is 152.68m^3 of reinforced concrete. If volume is divided by 550sqm, results a hypothetic concrete layer of 277mm thick for calculation purposes.

b) Concrete strips calculation:

For concrete strips calculation, cubic metres of concrete have been calculated and then, divided by the footprint area: 550sqm. Hence a hypothetic slab has been calculated for thickness calculation purposes.

There are 266.34m of 600x600mm strips. It makes 95.88m^3 of reinforced concrete. There are 69.47 m of 600x1000mm strips. It makes 41.68m^3 of reinforced concrete.

There is a total of 137.56m^3 of reinforced concrete from foundations strips. That would make a hypothetic continuous layer of reinforced concrete of 250mm used for calculations purposes.

c) Gravel and Insulation:

For sand gravel and insulation quantities, thickness is calculated the same way. Between concrete strips there is a layer of gravel 250mm thick and on top of that there is a 150mm Kingspan polystyrene insulation. Area of those materials is 380m^2. Total environmental impact for manufacturing is calculated and then divided by 550m^2 in order to have EE and EC by unit of area.

d) Dump-proof membrane

Dump-proof membrane is located at the very bottom of foundation. It´s considered a continuous layer of 3mm.

Foundation layers and its manufacturing impact data would be summarised as follows:

Table 6.30: Yoker Foundations layers composition

Layer	Material	Thickness	EE/m^2	EC/m2
(No)	(name)	(mm)	(MJ/m^2)	(KgCO$_2$e/m^2)
1	Concrete piles R1,5*15/30m	277*1	10.670,52	1.103,02
2	Concrete strips 600/1000mm thick	250*1	1.360,80	121,86
3	Compacted Sand & Gravel	200	32,11	2,01
4	Thermafloor rigid insulation 150mm (EPS)	150	304,70	14,69
5	Waterproof membrane	3	450,24	4,03
	Manufacturing Stage (A1-A3) Subtotal/m^2		**12.818,37**	**1.245,61**

6.5.2.2. Ground floor

The ground floor specification varies depending the type of area above. There are common area ground floor and flats area ground floor. For this case study, ground floor specification is considered always as the flat's ground floor for simplicity.

Ground floor Ground floor consists on a 175mm thick reinforced concrete slab on top of foundation concrete. Then a 50mm expanded polystyrene insulation is located between softwood battens, which are every 600mm, on which a layer of particle board is fixed. Last layer is a 22mm carpet as the internal finish.

Special mention to softwood battens is needed. Here, battens are located @600mm. Then, environmental impact by sqm is been reduced by its influence's area: 60% in order to achieve the final impact by m2. Ground floor specification is summarised as follows:

Table 6.31: Yoker ground floor composition in flats and common areas

Layer (No)	Material (name)	Thickness (mm)	EE/m^2 (MJ/m^2)	EC/m2 (KgCO$_2$e/m^2)
1-flats	Floor finish – general carpet	12	9,80	187,00
1-common	Floor finish – vinyl flooring	5	10,00	187,00
2-common	Light concrete screed	50	27,65	4,45
2-flats	Chipboard flooring	22	281,60	19,18
3-flats	Treated SW battens 50x50mm @600mm	50	21,25	1,53
4	Mineral wool insulation	50	87,15	6,72
5	Reinforced concrete slab	175	716,45	74,06
Manufacturing Stage (A1-A3) Subtotal/m^2		**Common areas**	**841,25**	**272,23**
		Flats	**1.116,25**	**288,49**

- **Superstructure: rest of elements above ground**

The superstructure of the building involves all parts above the foundations such as walls and floors, roof, including external cladding and internal finishes.

6.5.2.3. Upper floors

Upper floors consist on a horizontal structural CLT panel with insulated false ceiling below and timber battens between insulation with timber OSB boards and general carpet above. In common areas general carpet is changed by vinyl flooring.

As per ground floor, uppers floors will be always considered with general carpet as internal finish. In this case, all layers are also continuous layers. Hence, no conversion is needed. Layers would be the following:

Table 6.32: Yoker upper floor composition between flats and common areas

Layer	Material	Thickness	EE/m^2	EC/m2
(No)	(name)	(mm)	(MJ/m^2)	(KgCO$_2$e/m^2)
1-flats	General Carpet	22	9,80	187,00
1-common	Floor finish – vinyl flooring	5	10,00	187,00
2-flats	Timber particle board	22	281,60	19,18
2-common	Light concrete screed	50	27,65	4,45
3	Plasterboard	19	75,94	4,38
4	Softwood battens 50x50mm	55	21,25	1,53
5	Mineral wool insulation	25	43,58	3,36
6	CLT Floor panel	120*	656,88	47,62
7	Service zone (air gap)	100	0,00	0,00
8	Mineral wool insulation	50	87,15	6,72
9	Light metal studs @600mm	50*	6,36	0,54
10	2xPlasterboard	250	151,88	8,76
11	General paint (two coats)	0,1	21,02	0,87
Manufacturing Stage (A1-A3) Subtotal/m^2		**Common areas**	**1.101,71**	**265,23**
		Flats	**1.355,46**	**279,96**

6.5.2.4. Roof

The roof construction is similar to the upper floor. In this case roof CLT panels are slightly tilted for a proper water evacuation and more insulated for thermal comfort.

Table 6.33: Yoker roof composition

Layer	Material	Thickness	EE/m^2	EC/m2
(No)	(name)	(mm)	(MJ/m^2)	(KgCO$_2$e/m^2)
1	Roof membrane	3	450,24	4,03
2	Roof underlay membrane	3	450,24	4,03
3	Expanded polystyrene insulation	170	677,79	25,16
4	CLT Floor panel	120*	151,87	8,76
5	2xPlasterboard (fire protection)	250	16,80	314,16
6	Service zone (air gap)	150	0,00	0,00
7	Mineral wool insulation	50	87,15	6,72
8	Light metal studs @600mm	50*	6,36	0,54
9	Plasterboard	250	75,94	4,39
10	General paint (two coats)	0,1	21,02	0,87
	Manufacturing Stage (A1-A3) Subtotal/m^2		**1.937,41**	**368,66**

6.5.2.5. External walls

There are two different external walls specifications depending on the external finish used. There is a metal cladding finish in junction with a vinyl brick slip finish area.

a) The first finish for external walls is HPL panel cladding fixed to timber studs

b) ds and which is fixed to the CLT panels. This cladding is made with high density panels finished in different colours.

c) The second external wall finish is vinyl brick slips glued to a magnesium board fixed to timber studs and directly to the CLT wall.

Table 6.34 CCG Yoker Building Ext. walls and CLT areas

Elevations	West	East	North	South	Subtotals
Element	(m^2)	(m^2)	(m^2)	(m^2)	(m^2)
Vinyl brick slip (net area)	316,99	317,71	240,53	184,13	**1.059,36**
HPL cladding (net area)	185,40	184,29	139,00	352,84	**861,53**
Subtotal external walls	502,39	502,00	379,53	536,97	**1.920,89**

Both types are visible from all facades and respective areas for LCA calculation are stated previously:

Table 6.35: Yoker both external wall composition

Layer (No)	Material (name)	Thickness (mm)	EE/m^2 (MJ/m^2)	EC/m2 (KgCO$_2$e/m^2)
1-EW_1	Vinyl brick slips (Alumasc) (glue included)	4	219,60	164,23
1-EW_2	HPL board	8	804,00	37,40
2-EW_1	MgO carrier board	12,5	75,94	4,38
3	2 x Timber studs @600mm	100	63,75	4,59
4	Expanded polystyrene insulation	100	398,70	14,80
5	CLT Wall panel	120	640,32	46,42
6	Light metal studs @600mm	50	7,46	0,63
7	Mineral Fibre insulation	0,1	65,52	4,37
8	Plasterboard	12,5	75,94	4,39
9	General Paint (2 coats)	0,5	21,02	0,87
Manufacturing Stage (A1-A3) Subtotal/m^2		**External Wall 1**	**1.568,25**	**244,68**
		External Wall 2	**2.076,71**	**113,47**

6.5.2.6. Internal walls

Although Internal walls are understood as internal vertical divisions within the building, for calculation purposes, these are understood as per different types depending on their location within the building. There are three different types:

- "Within flat" - divisions within the same apartment.
- "Flat-Flat" - divisions between different flats, also called "partition walls".
- "Flat-close" - Divisions between flats and common areas. Hence, internal walls specifications vary depending on the adjacent elements/areas. Following this, there are three different internal walls, all having CLT panel as a core. On the tool, the last two are considered as party walls, living "internal" just for divisions within flats.

Table 6.36: Yoker internal wall (same flat) composition

Layer (No)	Material (name)	Thickness (mm)	EE/m^2 (MJ/m^2)	EC/m2 (KgCO$_2$e/m^2)
1	General paint (two coats)	0,1	21,02	0,87
2	Plasterboard	12,5	75,94	4,38
3	Expanded polystyrene insulation	50	199,35	7,40
4	Light metal studs @600mm	70*	7,46	0,63
5	CLT Wall panel	120	640,32	46,42
6	Light metal studs @600mm	50*	7,46	0,63
7	Expanded polystyrene insulation	50	199,35	7,40
8	Plasterboard	12,5	75,94	4,39
9	General paint (two coats)	0,1	21,02	0,87
Manufacturing Stage (A1-A3) Subtotal/m^2			**1.247,86**	**72,99**

6.5.2.7. Party walls

Party walls, as mentioned previously, divide flats from common areas (PW-1) and different flats (PW-2). Party walls dividing common areas will be treated as dividing flats to close just for simplification. The only difference between the two types is the increase of external insulation in the first one in 50mm more.

Table 6.37: Yoker party wall composition

Layer	Material	Thickness	EE/m^2	EC/m2
(No)	(name)	(mm)	(MJ/m^2)	(KgCO$_2$e/m^2)
1	General paint (two coats)	0,1	21,02	0,87
2	2xPlasterboard	25	151,88	8,76
3	Expanded polystyrene insulation	50	199,35	7,40
4	Light metal studs @600mm	70*	7,46	0,63
5	CLT Wall panel	120	640,32	46,42
6	Light metal studs @600mm	50*	7,46	0,63
7	Expanded polystyrene insulation	50	199,35	7,40
8	2xPlasterboard	25	151,88	8,76
9	General paint (two coats)	0,1	21,02	0,87
	Manufacturing Stage (A1-A3) Subtotal/m^2		**1.392,28**	**81,11**

6.5.2.8. Windows external door

External windows are defined as PVC frame windows with double glazed specifications. There are 360 windows within this project, with dimensions of 1,50 by 1,20 cm. These windows make a total glazed area of 656.49 m2.

Table 6.38 CCG Yoker Building windows measurements

Elevations	West	East	North	South	Subtotals
Element	(m^2)	(m^2)	(m^2)	(m^2)	(m^2)
Windows (net area)	147.72	146.79	194.28	167.70	**656.49**
Windows (count)	76.00	76.00	97.00	105.00	**354.00**

Table 6.39: Yoker windows impacts

Element	Material	Glazed	EE/m^2	EC/m^2
(No.)	(name)		(MJ/m^2)	(KgCO$_2$/m^2)
1	PVC framed	Double	1,715.28	87.50

External doors are security and fire doors. For calculation purposes are calculated as PVC framed doors.

6.5.2.9. Internal door

Internal doors are specified as timber framed doors, with dimensions 80 by 210cm. The door's leaf is made by a 5cm thick timber battens as main structure laminated in both sides.

Table 6.40: Yoker doors impacts

Element	Material	Type	EE/m²	EC/m²
(No.)	(name)		(MJ/m²)	(KgCO$_2$/m²)
1	External door	Fire protection	117,03	9,71
2	Internal door	Timber framed	47,57	3,79

- **Internal finishes**

Internal finishes involve the following construction elements:

a) Internal Walls or internal leaf of external walls
b) Ceilings
c) Floors

6.5.2.10. Internal wall finishes

Internal Walls or internal leaf of external walls. They are always assumed to be finished by a double coat of general paint over the plasterboards fixed with light metal frames to the CLT panels. There would not be any insulation within the light metal studs frame.as one plasterboard finished with two coats of general paint.

Table 6.41: Yoker: internal wall finishes options

Finishes	Material	Thickness	EE/m²	EC/m²
	(name)	(mm)	(MJ/m²)	(KgCO$_2$/m²)
	Plasterboard	12,5	75,94	4,38
Wall	General paint (two coats)	0,1	21,02	0,87
	General Carpet	22	9,80	187,00

6.5.2.11. Ceiling finishes

Ceiling specifications are all the same for all ceilings in both, flats and common areas. For calculation purposes ceiling has been taken into account as multiple layers made of 50mm mineral wool insulation and a total of 3 plasterboards 12mm thick each. There is an air gap between plasterboards for fire extinction. Lastly, ceiling is finished with a double coat of general paint. Specification has been stablish within the other components explained.

6.5.2.12. Floor finishes

Floors finishes are different depending if they are inside flats or on common areas.

a) Flats are assumed to be finished with a general carpet layer over a 22mm chipboard

b) Common areas are finished with vinyl floor 4mm thick over a 70mm light concrete screed on top of the CLT panel.

6.5.3. Results

The following table indicates the summary of material options evaluated within this project:

Table 6.42: material options for CCG Yoker project

Building element		Yoker CCG project
Foundation	Material	Concrete piles + concrete strips
	Insulation	Expanded polystyrene 150mm
Ground Floor	Material	Concrete slab 175mm
	Insulation	175mm expanded polystyrene
Upper Floor	Material	CLT Panel
	Insulation	EPS 45mm
External Wall	Int. Leaf	Light metal stud wall
	Ext. Leaf	CLT Panel
	Insulation	EPS 45mm
Internal Walls		CLT Panel
Party Wall		CLT Panel
Roof	Materials	CLT Panel
	Insulation	Mineral Fibre 300mm
External windows		PVC framed. Double glazing
External doors		PVC Framed
Internal doors		Timber framed
Internal Finishes		Plasterboard + general paint 2 coats
External Finish		Brick slips / metal cladding

Results show the following impacts by LCA stage for both indicators, having most of them due to the operational phase (B6).
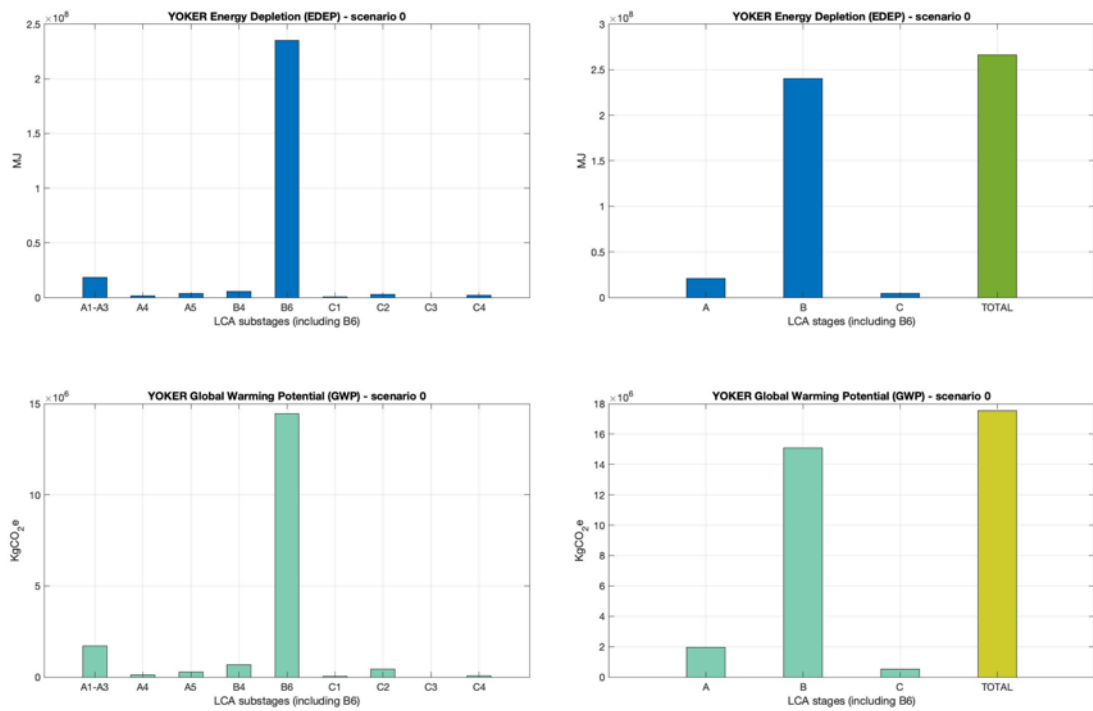
Figure 6.23: Yoker Building. Bar plots with results by LCA stages.
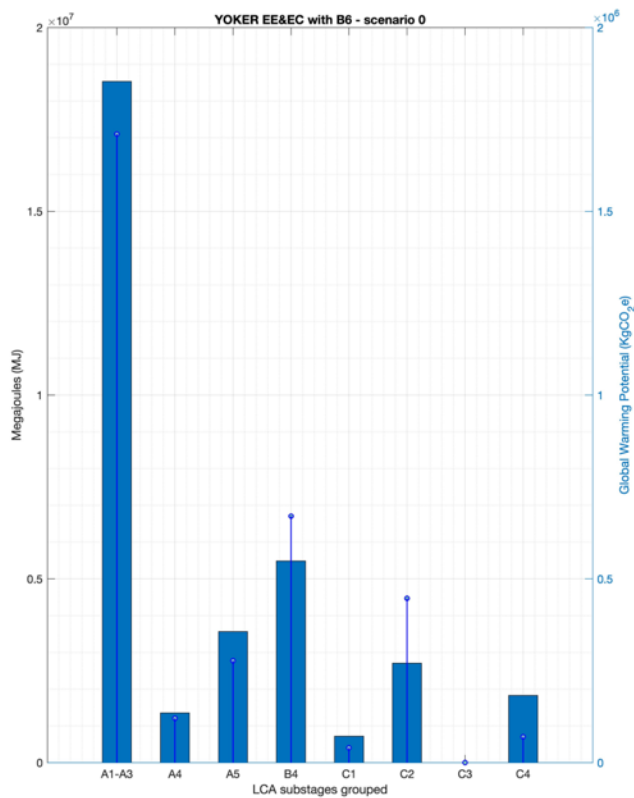
Figure 6.24: Yoker building. Combo bar plot with embodied energy & carbon results

Regarding the carbon impacts, we can see the following percentages by LCA stage:

Yoker: Impact by LCA stages
(% CO_2e)
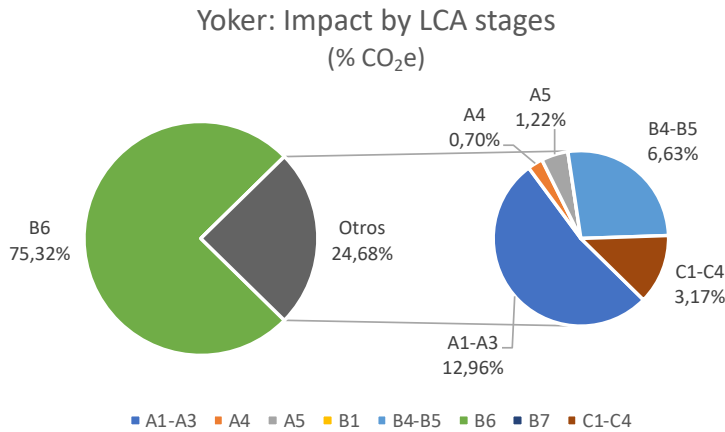
Figure 6.25: Yoker building. Pie chart with percentage of results by LCA stages

Table 6.43: Yoker building. Summary of carbon results by LCA stages

Results by stages - YOKER		SCENARIO	
LCA Stages		TonCO$_2$e	Fraction %
A1-A3	Manufacturing	2.487,87	12,96%
A4	Transport to site	134,47	0,70%
A5	Construction	234,92	1,22%
B1	Use	0,00	0,00%
B4-B5	Replacements and renovations	1.272,02	6,63%
B6	Energy use	14.458,55	75,32%
B7	Water use	0,00	0,00%
C1-C4	End-of-life	609,49	3,17%
Subtotal		19.197,31	100,00%

Results for manufacturing impact by building element would be the following:

YOKER - manufacturing impact by element
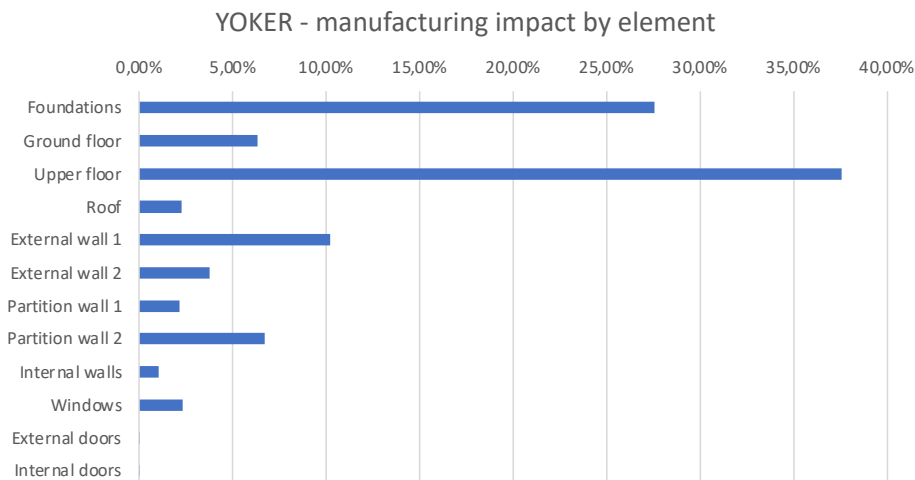
Figure 6.26: Yoker building. Bar results with A1-A3 stages impacts

As it is seen, upper floor has the greatest impact, as it was expected due to the 8 levels of the building. It is followed by the foundations due to the high used of concrete on for piles and raft beams.

In this case, different external and partition wall appear, indicating the manufacturing impact of each one, also involving different surface area covered by each type.

On the other hand, internal and external doors would have the smallest impact in terms of singular elements, knowing that the units or area of them are low.

This would give a very good view of all impacts of the different building elements and which of them should be studied in more detail.

Regarding the embodied carbon, this case study obtains, within the life cycle of the building, a result of 1236,66 KgCO$_2$e/m^2 (SIB). This is slightly higher than the current benchmark (1200KgCO$_2$e/m^2 SIB) but without having into account the carbon sequestration nor the precedence of the timber products. With these factors considered, the global figure of the embodied carbon would be presenting figures near the 900-1000 KgCO$_2$e/m^2 SIB.

6.6.   Conclusions

From this chapter, some conclusions could be appointed according to different criteria.

6.6.1. Case study 1: Cube building

With this case study, the evaluation tool proposed within this PhD have been tested as valid, since exact results were obtained for three different materials and options for all stages of the life cycle that are part of the scope of this research.

Once the tool has been verified, results show the difference between three different materials for external walls: brick work, concrete block and in-situ concrete wall.

Results show that the greatest impact is obtained with the in-situ concrete material, with almost three times the impact of the concrete block wall, which would be the more environmentally friendly of all of them.

Brick work wall would be the intermediate option, in term of environmental impact, having other properties that should also be considered on a construction selection such as soundproof insulation, installation process and economic factors that are not part of the scope of this simulation.

From these results, in-situ concrete should not be used in any case, since all stages perform with the worst results of the comparison except for the installation process in which impacts are almost the same as per brick work wall.

6.6.2. Case study 2: BRE Retrofit Building

With this case study, the adaptability and the different options of the tool have been tested successfully. Not only detached houses but also 4-in-block buildings are possible to be evaluated with the tool proposed. More sensible analysis will be performed on the following chapter but results, as a global and specifically by building stage, present figures considered within the normal values of a much more detailed LCA [83]. **This means that the tool not only gives an approximation to the reality but also a very accurate result for a pre-evaluation use.** Results about 950 and 1,000 KgCO$_2$e/m^2 (SIB) have been obtained, which are within the current benchmark indicated by LETI and RIBA of 1,000 KgCO$_2$e/m^2 (GIA), related to LETI band D. Both RIBA and LETI are two British organisations with great recognition of this theme.

Regarding the different options and cases evaluated, it is observed that scenarios with more material installed present a higher environmental impact. Both for energy and carbon indicators.

It should be needed a deeper analysis for building elements performance's evaluation, but it could be seen that some materials perform better than others, also obtained from the first case study.

For instance, for the manufacturing stage, strip foundation performs much better than raft foundations. However, for transport impacts, strip foundations performs better than the raft option. This is due to the great amount of concrete that need to be installed for the raft foundation, but in terms of transport, no gravel should be needed on site. Hence the different of impact between those stages. The best options should be evaluated according to the specific circumstances of any particular project.

Regarding the roof options, it is obvious from results that slate tiles have a massive impact in comparison with the ceramic tiles options. This is a clear conclusion for roof finishes.

It is also observed that the end-of-life works much better for buildings using more concrete blocks forms than brick work, due to the bigger circularity of the first ones that nowadays could be achieved within normal conditions.

6.6.3. Case study 3: Yoker CLT Building

With this case study, the tool's database has been tested, adding more uncommon materials and scenarios. Also, it has been validated for the LCA evaluation of much bigger development than 4-in-block buildings. CTL timber has been considered as well as other external cladding options with the tool performing correctly.

This case study does not take into account the possible carbon sequestration for the timber products, as explained on chapter 5, and indicates that timber is not always the environmentally friendly option. For that to happen there are some other circumstances that would need to happen, all of them having the sustainable forest resource and recycling of the timber products as a baseline. Only the first one could be confirmed for a project since the second one would happen in a 60 o higher years span.

7

CHAPTER 7: VALIDATION AND SENSITIVITY ANALYSIS

7.1. Goal and Scope

The purpose of this section is the validation of the new methodology proposed by this PhD project.

The principal aim which is pursued is to analyse the results obtained with the simulations performed and demonstrate that the new simplified method is valid for the purpose for which has been generated. This is, the environmental performance of the buildings in terms of energy consumption and carbon emissions including the analysis of the insulation material optimization results that the proposed tool is able to calculate

The secondary aim would be to test the proposed method and calculation tool against the different cases evaluated in order to validate it with the different possible building typologies and materials for which the database has been prepared.

A few case studies have been evaluated with the new Matlab tool, as stated on previous chapter, and same case studies are going to be analysed and compare with current benchmarks in order to see the correlations and differences and then be able to test the method.

This validation process does not only aims to get validate these results from the proposed LCA tools but to get also valid trends of the environmental indicators considered in order to show how the new method for LCA performs. This validation process aims to check the method itself and no the final figures only. The accuracy of numbered results, when talking about LCA, depends on the environmental database and characterisation factors that are taken into consideration when evaluating the product. In this case the product is a complete building for which the process ends up being very complex and with a lot of assumptions. As explained before, this research is about the method proposed and not about the accuracy of assumptions considered which could vary depending on the assessment.

The new tool has been generated in such a way that the database could be updated and change if new or specific environmental data is available for each evaluation. Hence it is possible and expected to achieve different results in global figures from the same LCA of buildings with different software tools but the differences between LCA stages should be similar, as explained on chapter 4.

The scope of this validation process involves the same environmental impacts as per simulation process explained on the previous chapter, such as embodied energy and embodied carbon from all LCA stages, including End-of-life, from the main materials that compose the building elements of the domestic buildings studied including the construction processes that they require.

Again, all materials accounting for less than 5% of the total mass of the building will be out of the scope such as fixing nails or adhesives…etc. It will also be out of the scope all potential furniture, equipment, facilities or its installations processes.

Case studies against this sensitivity analysis will be compared to are the mentioned on the previous chapter and global figures for embodied carbon databases as well as current benchmark will be commented. The index could be summarised as follows:

- Current environmental evaluations: database, impact methods and current benchmarks.
- Building from the indicated paper publication in which different wall materials options are evaluated.
- Refurbished building that belongs to BRE Innovation Park at Ravenscraig. In this case this PhD could performs 4 different scenarios with the same building due to the research and innovation nature of the project itself.
- CCG Yoker housing project with off-site CLT construction walls. This project aimed to perform an innovation itself with the CLT structure and results would need to show it in case carbon sequestration of those timber products would be considered.

7.2.   Approach to sensitivity analysis

7.2.1. Environmental database quality

Database of environmental impacts is currently one of the most popular discussions between sustainability experts. There have been some efforts trying to narrow this quantity of data with common documents, called "Environmental Product Declaration" or EPD, but there is still a long way to travel for common figures and datasets are to be used when evaluating building and its components from different companies and consultancy experts.

This task is difficult to approach since there are several certification programs to perform EPDs and to report those impacts, each one with its own validation systems and processes even though they are according to the relative standard. So that, even if the EPD of a specific product has been calculated according to current regulations [78] they will be difficult to be compared against other declarations of the same or similar products from other programs, as commented on Chapter 3.

These programs have mandatory and optional stages to be reported, meaning that they will not always have the same environmental information to be compared completely.

Regarding the database of this tool, it can be said that one of the weaknesses is the years of the environmental information included and the varying nature of the embodied energy and carbon figures of construction products. Variation of the data can come from different reasons:

- Changing sources of materials.
- Evolution on the manufacturing process of products.
- Changes on the electricity supply mix used for all processes involved.
- Evolution of carbon characterisation factors.
- This database shall be updated periodically to maintain updated the complete tool to in order to offer accurate result net data at the time of each evaluation get accurate results, according to the updated environmental impact of products available. In addition, it shall be expanded with additional materials and products, so the user options grow too.

Although, on the one hand, the tool has possibly this weakness, on the other hand, the intention is to develop a valid calculation methodology, regardless of the unitary environmental data of the materials considered. That is, the calculation matrix works independently of the database. The possible outdatedness of this data would affect the final net impact result, but not on the algorithm of the tool, which is one of the strengths.

However, ICE database has been used for two main reasons:

- Empirical nature of environmental impact data regarding the embodied energy and carbon. This means that even if it is not the most up to date information, it is real information and not only theoretical. Which give a higher degree of certainty in comparison with other datasets.
- It is available for free and there is no need to pay a high license to get all available data of construction products.

Furthermore, the environmental database of products accomplished, gives the information by square meter instead of by Kg of material. This becomes one of the biggest advantages against almost all datasets available within the LCA calculation tool giving the user a clear perspective of the impact of a complete construction element, which is a more comparable unit of measure rather.

It is more likely to know how many square meters the roof of a building has rather than the mass, or volume, of all products involved on that roof (concrete, reinforced steel, mortar along other products for either an expert and non-expert user. Hence, a global impact by construction element becomes a more natural figure to understand instead of each product unitary impact by mass or volume.

Regarding the different sources from which this tool gathers all the environmental and non-environmental data it can be said that there are not conflict of compatibility. Since each source of information is accomplishing one piece of data different from the other, they can be mixed to get all assumptions needed for a complete LCA assessment.

In fact, it is not possible to get all the dada used for the assumptions and methos of a complete LCA of a building from one unique source of information. For example, an EPD indicated the impact of a product, but does not indicate the percentage of material diverted from landfilling sites, or the on-site waste ratio. So other sources are a requirement for a complete assessment.

7.2.2. Impact method

When performing an LCA, the impact method is considered as all calculation and assumptions behind the results. In this case all calculations have been accomplished using the "Whole Life Carbon assessment method" explained by RIBA [125] and following the commented standard EN 15978 [3] about the framework that should follow every LCA performed within the construction works process in order to calculated the embodied carbon and whole life carbon measurements.

This impact method could set all calculations and possible assumptions that should be adopted when assessing these buildings in order to achieve a correct and accurate carbon figure, as well as other indicators. In this project, all these assumptions and calculation could be verified with the methodology explain on chapter 5 and Appendix A.

Impact methods and indicator will also vary with time since they also have the evolving nature when different factors are obtained. This is the case of all characterisation factors, indicating, among others, the factor for which all amount of GHG emissions should be multiplied by to get the accurate equivalent of CO_2 that will be used for the impact indicators. There al also some other varying factors regarding the impact method itself, indicating how importance is each of the different impact indicator for an end-point valuation.

In this case, since the assessment of this tool results on a mid-point method, characterisation factors will affect the database, as commented on the previous sub-section rather that to the calculation method within the Matlab tool. Hence, the need of maintain updated the corresponding database.

For products declaration and other environmental data of specific materials, the framework of the calculations and assumptions to be considered are indicated on the standard EN 15804 [78]. This regulation set out all mandatory stages that need to be considered and reported when declaring the carbon assessment of products. In this case, since the functional equivalent is the complete building, there is no need of comparison between products. Comparison could be made by construction element if functional equivalent is considered so.

7.2.3.   Uncertainty of input data and results

As commented, the tool has different sources of information for the complete database, that will me mixed with all user input data for any assessment. This means that an uncertainty of all variables and results produced by the calculation matrix is expected. The uncertainty comes, mainly from the following sources:

- Information on the database itself:
    o Environmental database.
    o Non-environmental database:
        ▪ Assumptions followed by the tool:
            • Materials
            • Reference service life
            • Wastage routes
            • Construction and demolition impact
            • End of life scenarios
        ▪ Transportation impacts
- Results coming from the calculation matrix

Possible uncertainty coming from the environmental database has been commented on the previous section 7.2.1.

Uncertainty coming from other non-environmental data is a common issue when performing a complete evaluation of a building and involving all LCA stages [126]. This uncertainty will always exist since there are no standards for this type of information beyond the reports that some prestigious entities have prepared such as RIBA, LETI or BRE along others within the UK. With this data it is possible to differentiate from the following:

- Intrinsic information of materials, such as density and thickness applied. This type of information can be validate using the project drawings and specifications. It can be analysed having a general construction and architectural knowledge. The way in which the amount of material is calculated by the tool is a very straight forward process, explained on Appendix A, so that a very small uncertainty on the quantities is expected. Hence on the manufacturing impacts obtained.
- Information regarding the reference service life of products. This can always be discuss since product can last for a longer period that the manufacturing assumption, depending on the maintenance status [127]. Although the green guide to specification information has been used for this thesis, since BRE

organisation was one of the PhD funders and gave complete access to it, other sources could have been used and they could also be valid ones.

- Wastage routes indicates the percentages of materials that are considered as waste within the manufacturing and construction process. Again, there could be no rule or guidance document more valid than a complete report based on empiric information, or government regarding the amount of waste produced or processed for the complete country or region. In this thesis, BRE wastage routes are applied for each material included on the database, considering valid the data used since the organisation which compile it is a recognised one.

- Construction and demolition factors have a bigger uncertainty than the previous factors commented. This is because they are process quite difficult to evaluate and monitor for real data information to be considered [128]. From among these, the main concerns applies to construction process of a new building rather than the end of buildings and their de-construction nor demolition process. Hence, monitoring data of energy and carbon flows is starting to become available from the first process but not for the second one. However, detailed data for both is limited on the literature and only for specific case studies.

- The end of life of the products includes the transport to either treatment plants or landfills and the processes to convert the waste into new usable materials in new supply chains. The same happens with all these processes as per the previous point, since manufacturing impact data has become a must for producers but not for treatment plants using the waste generated. However, they will be of great importance when the transition to amor circular economy will take place. In this research, rates coming from BRE incinerations and recycling reports have been used, bearing in mind that they are something changing drastically within the last years where there is a much bigger concern about minimising the waste production and the circularity of products.

Regarding the transport loads of the tool, included on LCA stages A4 and C2, the bigger uncertainty comes from the fact that all materials are assumed to travel the same distances with the same type of vehicle. This means the transport loads calculated by the tool are likely to be much bigger than the reality. Unfortunately, this can only be accurately calculated with real monitoring data from the construction process itself, which becomes an impossible task when evaluating a building on the early design stage of a building [129].

7.2.4. Current benchmarks

Although current benchmarks are considered as valid reference for comparison, this topic can be deeply discussed depending on the region or country in which the building is located, and the impact method used for the assessment [130].

In this case, RIBA and LETI benchmarks are considered valid for the tool developed since buildings are located within the UK and the database used for the impact method performed are based on UK products and processes.

However, it is noted that reference ratios and statistics from these benchmarks may vary from the reality of any specific projects since assumptions and factors are not indicted with them [131].

It can be seen from the results that the impacts, for the different stages, remain vary similar as the reference benchmarks mentioned, in addition to obtaining impacts per unit of area according to the ranges established in them. One main difference is the higher results on operational energy and carbon which results on a global higher percentage of impacts, due to that high reference values use for the operational stage of the building, commented on chapter 5.

CURRENT BUILDING REGULATIONS
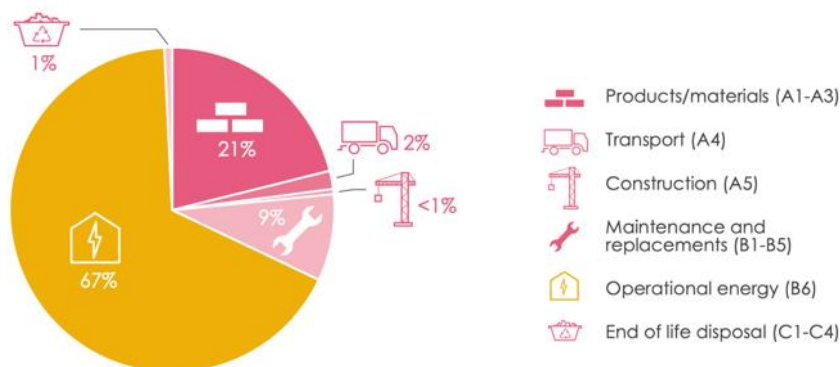
Figure 7.1: Residential medium scale impact benchmarks ratio by LETI

RIBA stablishes a reference of 1,000-1,200 $KgCO_2e/m^2$ (GIA), related to LETI band D-E for current LCA of buildings finishes before the 2020. Where LCA assessment for the case studies, calculated with the proposed tool, obtained results ranging from 920 $KgCO_2e/m^2$ (GIA) for the non-insulated option of the retrofit building to 975 $KgCO_2e/m^2$ (GIA) for the scenario with a higher embodied carbon impact.

7.2.5. Conclusions

As stated before, all simulations on this PhD have been made with the proposed framework which is in line with current regulations EN 15978 [3] and the "Whole life carbon Assessment impact method of RIBA [125]. Environmental data such as construction and demolition or waste disposal impacts have been used in accordance with those documents when performing the evaluations.

We can see how the complete embodied carbon results of the BRE and CCG Yoker case studies, in which the functional unit is the complete building, are coincident with the current "business as usual" scenarios of RIBA, following the RIBA 2021 report [83], with both embodied carbon indicators between the current practice "business as usual" of 1,000 $KgCO_2e/m^2$, stated by LETI, and the RIBA benchmark of 1,200 $KgCO_2e/m^2$ [132].

In this regard, it is possible to state that the proposed tool gives out results within the range that RIBA and LETI stipulate as normal for buildings using common materials and construction processes. It could be understood that the tool validation is correct.

7.3.   Load-bearing walls materials

7.3.1. Different materials options

Case studies demonstrated that the better material selection the better environmental results could be achieved in regards the embodied energy consumption and carbon emissions. This is only possible when decision-making tools, such as the proposed in this thesis, are used upfront the construction process has begun. Otherwise, as indicated on chapters 1 and 2, benefits from late decisions will achieve smaller with a higher associated cost.

To assess these environmental impacts, different material options have been integrated into the tool, and comparison between them is essential if low impact is sought. First case study commented is the load-bearing walls comparison where same simulations with exactly same quantities have been performed in order to see how the simplified tool performs against other calculation with already valid tools [40]. As chapter 6 demonstrate, results are the same, hence, the tool seems to work correctly in terms of calculations and environmental database.

Table 7.1: Cube Building simulations results obtained for all materials evaluated

Material	A1-A3	A4	A5	C2	C4	Totals	Unit
Brck wall	4,919.04	287.69	1,835.53	287.69	442.81	7,772.75	KgCO2e
	51,997.22	4,868.99	30,222.18	4,868.99	11,516.49	103,473.88	MJ
Concrete block	2,821.54	130.53	659.33	130.53	200.91	3,942.83	KgCO2e
	21,507.84	2,209.13	10,855.97	2,209.13	5,225.20	42,007.27	MJ
Reinforce concrete	5,850.72	444.97	1,831.85	403.41	606.36	9,137.32	KgCO2e
	49,537.08	7,531.02	30,161.67	6,827.54	15,770.21	109,827.52	MJ

Level 1 (all spans with the same thickness)

In this case different wall options were evaluated resulting on the following comparison:
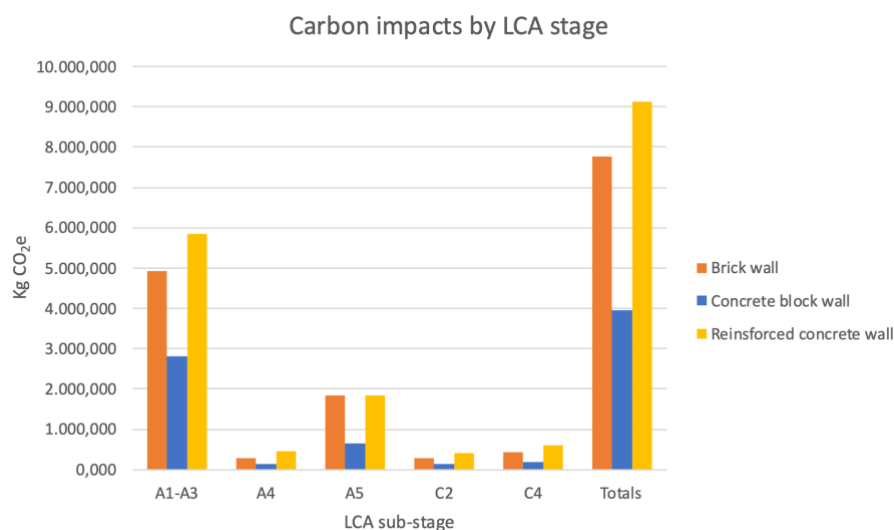
Figure 7.2: Carbon impact comparison for material load-bearing wall options

214
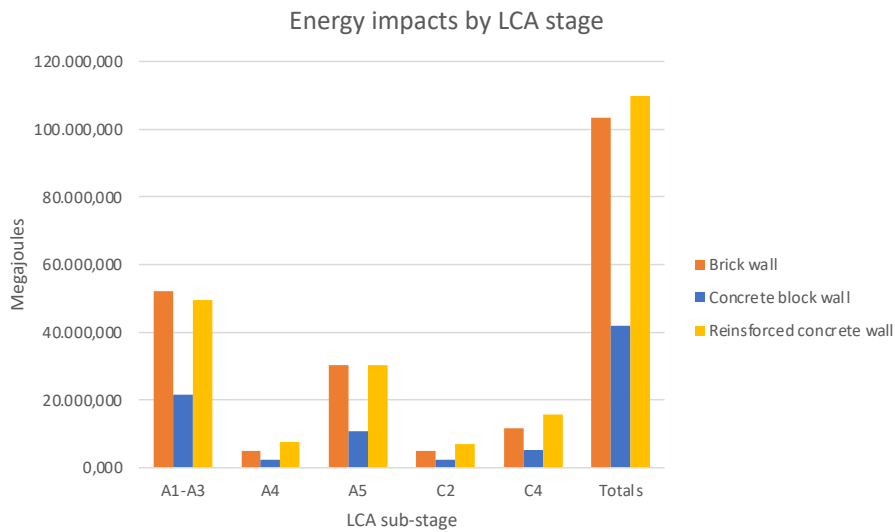
Figure 7.3: Energy impact comparison for material load-bearing wall options

For these materials concrete block material would result on the lowest overall impact, followed by fired clay bricks and in-situ concrete.

In addition, life span of this material is usually longer than the reference study period, as well as per the other options, meaning that no replacements are needed during the life span, hence, no impacts appear for the operational stage.

This would happen either embodied carbon emissions and energy consumption, where clearly concrete block are the best case that should be targeted.

7.3.2.   Construction and end-of-life impacts

In terms of impacts arising from on-site construction works, current extended practice is to use estimations for electricity, fuel and water consumption [23].

As indicated on chapter 5, on-site impacts also involve those arising from the installation wastages. It is also usual to incorporate some wastage estimations for those construction materials or breakages arising for the actual human activities happening on-site [115].

This is the case, where results may vary depending on the density of materials when same areas are involved. This is the case of this first comparison, since it could be seen that for brick and in-situ concrete walls, construction impacts are relatively similar, but much smaller concrete block since performs better. the difference lies in the different densities of the elements, in combination with the estimated waste percentages.

Same happen with end-of-life scenarios where percentages diverted from landfilling and densities are similar [76]. Those materials with lower density and/or percentage of waste sent to landfilling would have less embodied impact arising from the building life cycle.

7.3.3. Conclusions

Conclusions from the evaluations of the first case study and the Ravenscraig retrofit options, are commented as follows.

In terms of load bearing walls, it is noted that concrete block walls are more sustainable than brick and on-site concrete walls. Concrete blocks, for manufacturing stage, have a lower unitary impact than bricks walls or on-site concrete whilst installation process would be similar in terms of electricity of water consumption.

In this regard, in addition, concrete blocks have the lowest density of the three options commented, inducing that at the same percentage of waste by unit of area, less mass of debris would be produces. Hence, less global material mass would need to be transported to either landfilling site or waste treatment plants resulting on a lower impact at the end-of-life stage.

Furthermore, in terms of circularity, concrete block walls could be crushed and used as aggregate for other projects or uses, same possible treatment as bricks. In this case no special advantages come from this process.

This analysis would conclude that, if possible, projects would need to incorporate this load-bearing wall made of concrete blocks if embodied carbon is targeted.

Regarding the tool proposed and how construction impacts have been integrated, on the one hand, the proposed tool uses the mentioned scenarios for electricity and fuel consumption for early assessments, since they don't have the possibility of knowing those impacts and estimations are obliged for a pre-evaluation. On the other hand the proposed tool has its own calculation matrix for wastages arising for materials installed by workers, indicated on the installation waste percentages on the material database on appendix B.

This would benefit the proposed tool for a more accurate result from these on-site impacts and also it would let the user to update those percentages in case some others are known, or different options want to be compared. Although on-site consumptions are not usually monitored, they only would need to incorporate at the specific stage and element at the spreadsheet in which results are indicated, in case existing buildings are evaluated.

7.4.   UK common domestic buildings

The second case study allowed to evaluate some retrofit options of a very common domestic building within the UK: the 4-in-block. This typology has been extensively built in the 50s so that they are now to be either retrofitted or demolished in order to improve the future building stock and carbon emissions coming from it. This has become a strategic initiative for authorities while approaching climate change targets within developed countries.

7.4.1.   Retrofit options

When either retrofit or demolition upgrades are weighed the building needs a major renovation process. Only LCA evaluations in junction with energy simulations coudl achieve a real answer according to the planned investment. In terms of social and environmental impacts, retrofit solutions are always more valued since the main core of the building does not need to be re-manufactured and installed, but possible social disruption come into action. Hence, a disturbance will always be made.

In this case study, different retrofit options are evaluated from the scenario called 0 where no insulation is considered, simulating the possible current state of a large building stock within the UK and Europe. In those comparisons, for which this example was built be BRE at its innovation park, internal and external insulation options, as well as different external wall finishes are considered, simulating possible real scenarios where the building has families living in, hence external renovation would take place, or not, and internal retrofit could be accomplished.

Although it is the case that socially could be a better one or the other options, in terms of environmental impacts it does not affect substantially the evaluation. In this case, operational consumption has been maintained equally for each solution, but it would be necessary to simulate the energy demand for each scenario in order to see how that demand could change with every insulation option and position appointed.

In case demolition and new building projects are selected, this case study would be beneficial since different material options were studied for the same building typology. Hence best possible solutions could be achieved from evaluations for several building elements.

7.4.2. Foundations

Regarding the foundations, two different solutions were studied with the Retrofit Building case study. Obviously, this is a building element which cannot be change nor renovated easily when retrofit projects are in action. However, this comparison let the potential user know how both solutions perform as well as the different impacts within al life cycle sub-stages. Differences are indicated as follows:

Table 7.2: Carbon impact comparison for foundation solutions

TonCO$_2$e	A1-A3	A4	A5	B1	B4	B6	B7	C1-C4	Subtotal
Strips foundation	17.29	4.82	1.87	0.00	0.00	0.00	0.00	12.22	36.31
Raft foundation	31.16	3.45	2.67	0.00	0.00	0.00	0.00	8.77	46.05
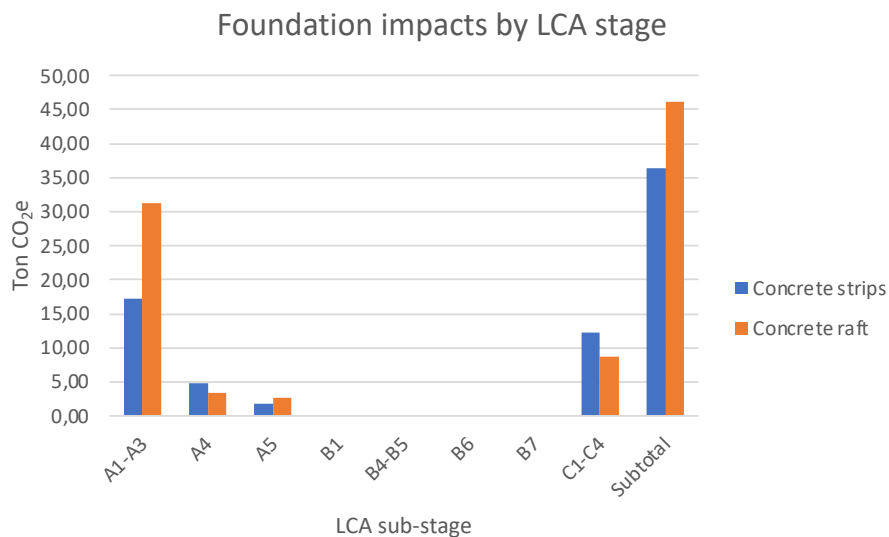
Figure 7.4: Carbon impact comparison for internal foundation solutions

It is possible to see how the solution of "Concrete strips" has a much lower overall environmental impact. Although all the difference is caused for the lower manufacturing impact of materials and quantities involved. It can be seen that transport and end-of-life scenarios perform not as well as the first stage. This is due to the high utilization of gravel, which has a very low initial unitary manufacturing impact but transportation to site and to end-of-life treatment plant makes impacts rise.

However, globally concrete strips perform better than concrete raft in terms of environmental solutions to be considered.

7.4.3.   Internal and external wall solutions

For this second case study, the retrofit building from BRE, also different options have been analysed with different wall solutions having the following results.

Internal wall comparison

Table 7.3: Carbon impact comparison for internal wall solutions

TonCO$_2$e	A1-A3	A4	A5	B1	B4	B6	B7	C1-C4	Subtotal
Single brick wall	20.98	1.73	1.40	0.00	6.43	0.00	0.00	4.38	35.04
Concrete block wall	13.45	1.76	1.03	0.00	6.43	0.00	0.00	4.46	27.12
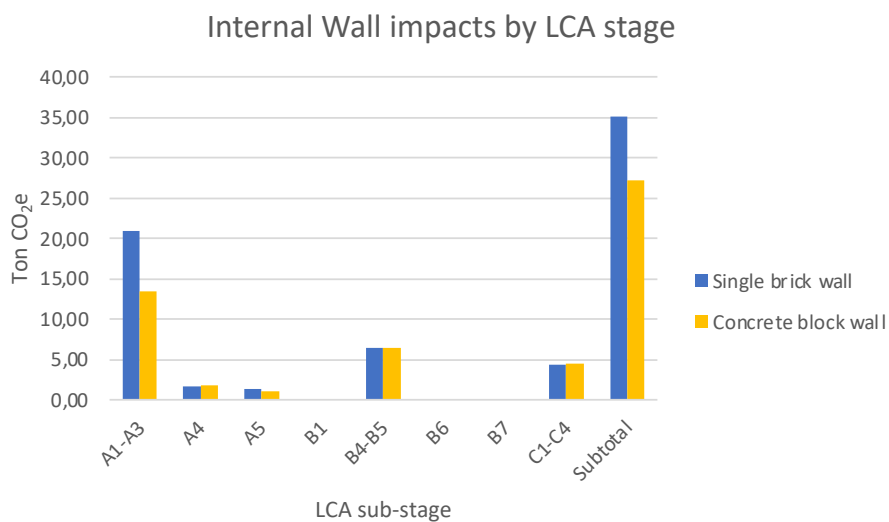
Figure 7.5: Carbon impact comparison for internal wall solutions

From the internal wall comparison, it could be noticed that any wall with some concrete block leaf involved result on a lower impact, same analysis as per the first case study. Brick walls could possibly have other better properties such as soundproof insulation or slight better thermal control but worst environmental performance in terms of embodied energy and carbon emissions.

External wall comparison:

In terms of wall material, the same conclusion from the previous point is valid, so no further analysis will be made in this regard. The solutions analysed for insulation and finishes options are the following:

Table 7.4: BRE Ravenscraig Building external wall description

Scenario	Internal leaf material	Insulation material	External finish
Scenario 0	Single brick wall	-	Lime & Render
Scenario 1		Mineral wool	
Scenario 2		EPS	
Scenario 3	Concrete block		Brick Slip

In terms of insulations material, it could be seen how mineral wool performs better than EPS from comparison between scenarios 2 and 3 where the only difference would be this insulation type. Although it would need to be completed with thermal comfort characteristics and how they would benefit the operational energy consumption which for this thesis have been fixed through benchmarks explained before.

Table 7.5: Carbon impact comparison for external wall solutions

TonCO$_2$e	A1-A3	A4	A5	B1	B4	B6	B7	C1-C4	Subtotal
Scenario 0	24.57	1.96	1.50	0.00	2.57	0.00	0.00	4.98	35.74
Scenario 1	25.85	1.97	1.60	0.00	3.83	0.00	0.00	5.01	38.41
Scenario 2	29.92	2.07	2.01	0.00	6.59	0.00	0.00	5.25	45.85
Scenario 3	24.75	2.09	1.76	0.00	6.59	0.00	0.00	5.31	40.51
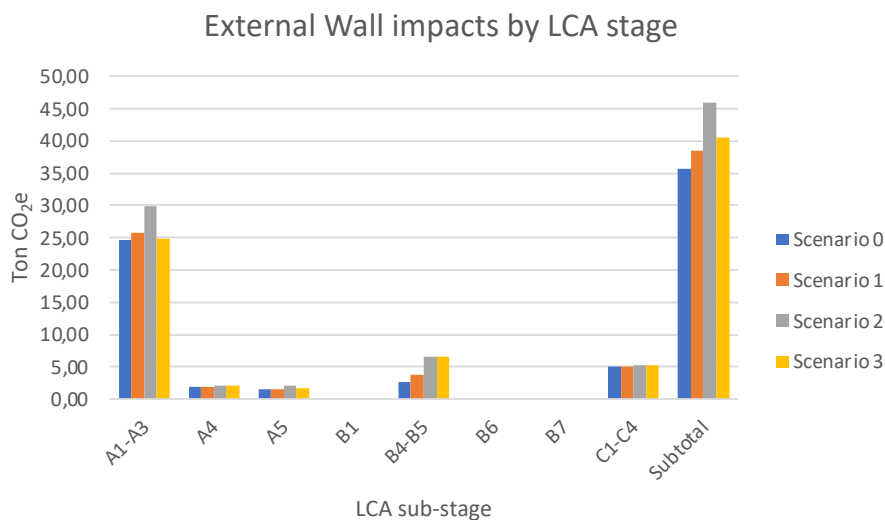
Figure 7.6: Carbon impact comparison for external wall solutions

Furthermore, the scenario 3 indicates that when introducing one of the wall leaves made of concrete block instead of brick work, impacts go down. This could be interesting when targeting expanded polystyrene solutions, with higher impact than other insulations, but willing to lower the overall impact with the load-bearing element.

7.4.4. Roof finishes

Regarding the roof options compared, as indicated on the following image, different external finishes were compared, resulting on a better performance for the ceramic tiles finish rather than slate slips if carbon emission figures are stated but the opposite in case embodied energy is targeted.

Table 7.6: Carbon impact comparison for external wall solutions

TonCO$_2$e	A1-A3	A4	A5	B1	B4	B6	B7	C1-C4	Subtotal
No INS + Slate tiles	19.14	0.25	0.62	0.00	11.90	0.00	0.00	0.64	32.67
MW + Slate tiles	20.13	0.26	0.70	0.00	12.88	0.00	0.00	0.66	34.75
EPS + ceramic tiles	14.81	0.29	0.60	0.00	7.31	0.00	0.00	0.75	23.75
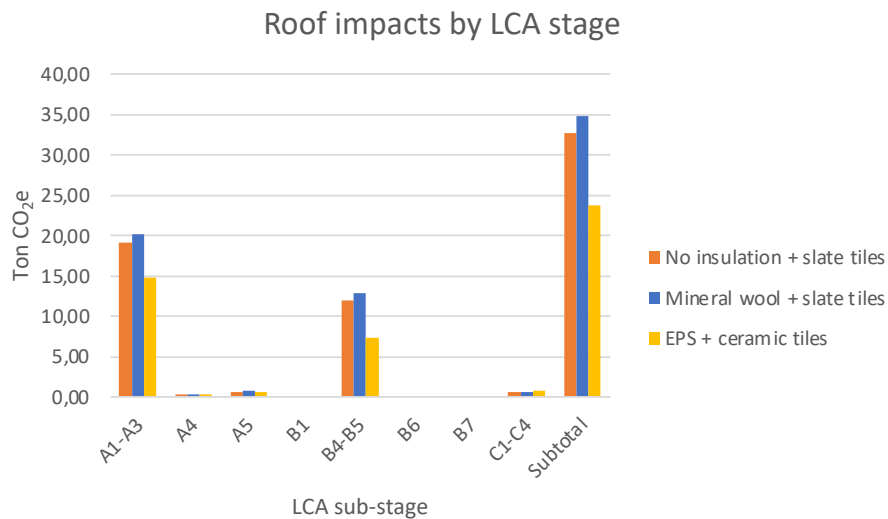
Figure 7.7: Carbon impact comparison for roof solutions

As indicated previously, if insulation options are evaluated, it could be seen that at the same thickness, mineral wool would perform slightly better for carbon emissions and more differentiated for embodied energy. However, this analysis would need to add thermal performance into considerations since installation impacts and end-of-life scenarios are relatively similar for both solutions.

Following this analysis, from the roof comparison graph it could be said that ceramic tiles has substantial less environmental impacts than slate tiles. The overall impact for the scenario 3, in shich EPS is used instead of mineral wool, is performing much better that even the scenario where slate tiles are placed with no insulation at all. It makes not only perform better for manufacturing but also for all other sub-stages involved within the building life cycle.

7.4.5.   Conclusions

As mentioned previously, from a environmental point of view, it is not much relevant if the retrofit work is performed from the inside or the outside of the building. It could only disturb the people that live within the building. Bearing in mind that any construction work, even the smallest one, is always a disturbance for the neighbours.

If sustainability is seen as a global, where social factors are included, then external retrofit option may be the best possible solution for renovation works.

If new projects are to be design within this typology or similar characteristics, a wide range of best possible solutions have been indicated.

This is the case of foundations, for which strips perform much better in terms of environmental impacts, rather than raft foundation in which more reinforced concrete is needed even though less transportation impact may occur.

For load-bearing and internal walls, the intention should be to use as much concrete block walls as possible against brick walls or in-situ concrete solutions where applicable. In case those walls are insulated, mineral wool, with the same thickness of other insulation types performs much better and. It gives better possible end-of-life options for recycling and reusage.

Last elements from the building envelope is the roof. While aesthetics are not part of the equation, ceramic tiles should be used rather than slate ones. Impact with these ceramic solutions would be incredible lower and performing also better within the other sub-stages and end-of-life scenarios are similar between them since they could be reused with minor restoration treatment.

Regarding the applicability of the tool, and its performance, with this case study the tool has been tested for retrofit options solutions and also for comparison at early stages of a project. This could be quite important for pre-evaluations assessment since they help substantially when a design is to be developed from design stage. It has been indicated that, for a specific building, some solutions have much less impact in terms of embodied energy consumption and carbon emissions. Hence, the tool could be used for the purpose it was primary design.

Discussions may follow these conclusions, some of them are commented on the following chapter. However, material options are greater each time and possible solutions are innovating with each project as the construction sector continues to redefine its physical and industrial boundaries.

7.5. Material innovation and buildings operation

7.5.1. Low carbon and carbon sequestrating materials

Case studies 1 and 2 showed how comparison between different options are the correct strategy to lower the embodied environmental impact due to conventional building materials options for common building projects. Both projects were not compared against innovative typologies such as the Yoker project which uses as a main material, for eight-storey load-bearing walls and upper floors, Cross Laminate Timber (CLT).

In this case, since timber was the only structural material, no direct comparisons were evaluated to see how difference other structural materials would have performed. This is because structural engineers would have been needed for equivalent solutions with other structural materials and the complexity of those solutions made very difficult to be obtained within this thesis project.

However, both the environmental database of this research, where materials impacts are listed and chapter 6, where impacts of building elements were indicated for each case study and scenario, indicate that manufacturing impact of timber products are not as low as it could be imagined, without carbon sequestration. This situation is caused why for a timber construction product to exists lots of processes need to happen, as well as several years of growth and maintenance before trees can be cut and processed to produce construction timber products [133].

On the one hand, it is true that a tree, throughout its life, sequestrates carbon on a normal basis. For this to be considered, that tree would need to live for around 25 to 35 years, depending on the species [134]. Also, the quantity of CO_2 captured could be calculated, as indicated on chapter 5, but there is always a big level of uncertainty on that figure.

On the other hand, common end-of-life scenario for timber products is incineration, which is a process from which lots of CO_2 emissions are released. Hence, cancelling almost all possible benefits previously obtained by carbon sequestration during the tree growth [135]. Despite this fact, the incineration could be used for either heat energy recovery or thermal comfort.

These are the reason why CO_2 carbon sequestration from timber products are often not considered within the manufacturing sub-stage while performing LCA of buildings and usually are indicated as "Biogenic carbon" as possible benefits from those products in which timber is used [133]. Almost all of these calculated benefits are allocated within the A1-A3 sub-stage as it is though that would be part of the raw material process.

Despite the carbon sequestration or manufacturing impacts of timber products, there are some sustainable certificates that indicates how the forest had been managed. This is because, as natural resources, they could have a quick end if no more tree feet are planted. Hence, FSC and PEFC demonstrate the sustainable origin of those timber products [136].

Although carbon sequestration within this thesis has not been considered for the reasons stated before, the fact that timber products manufacture does not have very little impacts bring to consideration the importance of lower impact materials that all constructions designers should consider in order to have more sustainable solutions for projects in which manufacturing impacts want to be mitigated.

This thesis reveals that pre-evaluation at early design with different material options is crucial in this regard, within a sector under continuous innovation and industrial development with more and more efficient strategies.

7.5.2.   Importance of transport loads

As stated on previous chapter, transport from factory to the construction site of all materials could range from 2% to 5% of the global embodied impacts of energy and equivalent carbon emissions. That would be the normal average percentage [137] for this sub-stage according to current benchmarks. It is

In this case study, since timber products came from Austria, where the Stora Enso factory is located, transport load is much higher for these products. All other product were obtained locally located or as per usual within the construction sector. This fact produced the increase of impact for this stage A4, since transport mode for CLT had to consider truck transportation until the Netherlands port, freighted shipment until UK port and then truck transportation until products reach the final destination.

These transportation loads and routes are not usual for conventional construction, warning about the possible little benefit that can be obtained when using wood products in construction. If timber production factories are nor developed enough for product to be locally obtained it could lead to massive emissions for other processes such as transportation or even installation.

7.5.3. Operational impacts

Although operational consumptions fine calculations, due to energy consumption and any fuel usage during the life span of the building, are not part of the scope of this research, regular consumption and good practice benchmarks are integrated within the tool as indicated on chapter 5 and 6 [106]. These benchmarks could lead to higher consumption and operational impacts than more detailed energy simulation could obtain for the same buildings due to the age of the information that has been considered as a reference.

This is the very noticeable within the YOKER case study, which was constructed to have a very low operational impact due to the high air tightness and great thermal performance of the building envelope. Additionally, if energy modelling was performed, those figures could be included on the final results for a more accurate assessment of the operational stage.

Current practice indicates that operational impacts could be around 120kWh/m^2/y following RICS [83]. This could range between 60% and 70% of the total building impact [84].

Although it has always been the greater impact of the LCA of buildings, new technologies and more efficient performance of facilities, linked to increasingly more efficient building envelopes have demonstrated that these impacts are getting lower and lower as the embodied part rises [137].

The trend to the future energy consumption has already been appointed to all-electric programs, which could control the emission factors as they are innovating and investing on renewable generation programs and closing gas and other fossil fuelled thermal plants for electricity production.

7.5.4. Conclusions

In terms of embodied carbon, timber products could be considered as low carbon material under certain circumstances, if carbon sequestration is to be considered. But it would need to be clearly stated how carbon sequestration has been calculated, what species are considered as well as the origin of that material with the corresponding certificates.

Additionally, it would be beneficial if transportation is reduced to the minimal distance as possible, being also needed to be considered in advance when material options and comparison were made. As indicated before, transportation could account for a high percentage of impact within the LCA of a complete building. Hence avoiding long distances could be seen as a sustainable strategy until other industrial modes and innovations appear such as full electric or hybrid heavy freighting good vehicles.

If operational carbon is to be involved, current benchmarks could be used, but real energy simulation software should be considered if more detailed and specific criteria want to be involved.

If operational impact is lowered through design strategies, embodied part of the building gets the greater concern regarding the global impacts. Hence, low impacts products get importance and early design options should be appointed in order to obtain better results upfront the construction process starts.

Future possible works for this thesis could be the integration of energy simulation results or variations within the current consumption benchmarks depending on the type of building assessment. It could also happen to avoid any operational impacts since that consideration itself is already widely attended by specific work groups and programs.

8

CHAPTER 8: CONCLUSIONS AND DISCUSSIONS

8.1.   General conclusions

As outlined at the beginning of this thesis, the main research question addressed by this work is:

- To what extent do the Life Cycle Assessment tools, designed to evaluate buildings, cover the current needs to achieve the mandatory embodied and operational decarbonisation and optimization objectives?

The main objectives set out on chapter 1 were defined:

I.   Bridge the existing low correlation between environmental assessment tools and reality. This also include the possible template of general information, building measurement and physical description when addressing a LCA of buildings.

II.   Study and approach the whole building process and stages, from a holistic point of view, considering environmental impacts.

III.   Review the existing literature regarding LCA impact methods and tools.

IV.   Establish a transparent methodology for LCA calculation for new and existing domestic buildings, able to be applied at early design stage.

V.   Generate an updatable and easy to read environmental database of construction materials, expressing impacts by unit of area, included in the most common building typologies within the UK.

VI.   Establish a calculation tool for environmental impact due to construction material's transportation, using different ways of transport.

VII.   Incorporate a user-friendly and decision-making tool with calculation software to address the LCA of buildings including the optimization calculation currently necessary.

VIII. Set future possible routes for LCA tool development and certification process.

The answer to this research question, as well as the specific works that meet each of these objectives are presented below, indicating the chapter and remarkable outcomes arising from the thesis sections.

8.1.1. The importance of LCA on the built environment – II + III

Chapter 1 presented the introduction, construction and domestic sectors and the brief historic LCA framework that this thesis is based on. Followed by chapter 2 in which this research presented the current climate change and a deeper analysis of sectors previously mentioned generating the wide and specific context in which this project sits. In conclusion it could be said that building sector need to pursue the achievement of net-zero embodied carbon buildings and low to zero energy demand performance during the operational stage. This would only be accomplish using LCA tools and methods properly.

Chapter 3 presented a detailed study about how the LCA of buildings is performed, indicators and impact methodologies, indicating how it is currently approached. Objective II has been met with this complete approached and study as well as objective III partially, being completed with the following section based on chapter 4 outcome regarding LCA certifications and tool research.

8.1.2. LCA as a sustainability tool – II + III

As indicated on chapter 4, LCA tools have become essential in either product and building level. They are used for products evaluation such as construction material i.e. a concrete block, or complete buildings impact performance and also as part of the rating or certification schemes. All of them are usually incorporated too late on the building process, with low capacity for transformation and incorporate mitigation measures.

Current evaluations often try to simplify LCA methods by avoiding some of the input information or generalising in some respects. Unfortunately, this means that sometimes very important issues such as the site-construction stage or end-of use stage are left out thereby reducing the accuracy of the study. Most results tend to relate to environmental performance assessments during the operational stage and, since there are a wide variety of tools on the market, is very difficult to compare the assessment of the same building from them. Every tool uses different weighting units for the "Environmental Impact Analysis", different inputs and outputs data and also alternate reference databases. The majority also does not include accurate end-of-life, financial or social aspects in their evaluation framework as these parameters would further complicate the assessment procedure. Nor optimization or carbon strategies mitigation systems.

All LCA tools and certification systems study are presented on chapter 4, completing the objective III achievement, while helping to lay the foundation for the proposed method and tool development indicated on chapter 5.

8.1.3. Environmental method – I + VI

When performing the LCA of new buildings, the assessment tool should be able to grant a decision-making mechanism rather than a testing calculation. That tool should consider all the process from cradle to grave of a building, from manufacturing process to end-of-life expected issues. Sometimes is useful to have a simplified conceptual model to be used upfront, and then a more detailed assessment to give as a final global result.

When existing homes are analysed, the tool should give us access to the best options, these being the most sustainable in terms of overall energy consumption (construction or total renovation + use + end of life), current environmental impact of all processes to be carried out for the home/building, including material recycling with existing techniques and innovations in that field.

Finally, and not least important, the tool should consider the final economic value of the project to assess their feasibility and the load that the user will have to suffer.

This LCA evaluations should also include real data about transportation, instead of assumptions commonly considered. This brings to light the importance of the tool's database, not only for products but also for all processes involved, including in-situ and off-site works related.

All those characteristics have been implemented on the proposed calculation tool which method has been explained on chapter 5, helping to meet objectives I and IV.

8.1.4. Environmental databases – V

Even though many times global lists of environmental impacts of building products have been attempted, it supposes a major task since each country has different parameters with which impacts are measured. Electricity mix varies even from different regions within a country.

There is a general lack of expertise and transparency for these datasets for which adaptability and unitary values are a must. At least within the same country or area where same climate conditions and natural resources are shared.

Datasets has also the handicap of being under continuous development. Periodically updates must be released since efficiency in construction industry is improving with massive steps.

All these factors indicated on chapter 4 helped the initiative of proposing a new dataset of environmental impacts of products, not only by unit of mass of material, as per usual on current datasets, but by unit of area of that product as stated on the corresponding appendix B of this thesis allowing the achievement of the objective IV.

8.1.5. The development of a transportation impact calculation tool - VI

As mentioned before, for a calculation tool to have impacts due the transportation of materials from factories to construction site, environmental impacts of all modes of transport should be considered. This includes the capacity and load percentage of those vehicles.

For this matter, a transportation calculation tool was stablished along the global calculation tool, achieving objective VI and helping the simulation process to obtain accurate evaluations resulting from transportation to from gate-to-site and from site-to-landfilling site.

8.1.6. The simplified calculation tool

Chapter 5 presented the method for the simplified LCA tool proposed, including other calculations needed for it to be used on its primary purpose.

On chapter 6 simulations of all case studies are explained, involving the various processes commented and indicating results showing how all parts are synchronised and perform resulting on the assessment of three different buildings. Some of them present different options within the same building element so materials comparison could be analysed.

On chapter 7 the validation process

The objective VII and in accordance also objective I, are accomplished as indicated within these three chapter because of the complete LCA process obtained. This process includes the project description introduction, general information and measurements of the building, physical description within the Matlab tool, the calculation matrix itself and validation of results showed for each case study through previous chapters.

8.1.7. Key findings of the research

The principal aim of this work was to improve the way buildings area assessed throughout its life cycle in terms of embodied energy and carbon equivalent in order to improve the sustainability performance of the construction sector.

There is a big gap between real buildings and digital twins in sustainability assessment tools that doesn't let us identify the right direction to improve the sustainability of buildings.

To reduce this existing gap, several important findings are indicated below, indicating the possible future work to expand and further improve the proposed simplified method, which is the last of the objectives of this thesis:

- Constant update of environmental data of all products involved is needed.
  The environmental data used for impacts allocations within building products and construction elements needs to be analysed. In this thesis, environmental data used as a reference has a few years, so probably numerical results are not valid for current building projects executed after 2022. This is why the comparison of results obtained from the tool against RIBA and LETI benchmarks are made using the "business-as-usual" references.

- Impacts due to material transportation.

  Transport environmental loads account for an important part of the energy and carbon embedded in the building's life cycle. That is why it seems essential to develop a tool capable of calculating this performance in detail such as the program developed for this tool. This program is able to calculate transport loads of materials selecting the type of vehicle and the mass transported in percentage loads. This way, is possible to select 50% load of mass for A4 stage, which is nearer the reality since freighting good vehicles get usually fully loaded by volume, accounting for half of the mass capacity, rather than by mass.

- Monitoring the construction process

  This monitoring work, with a detailed methodology, is a must and will give direct and real data from construction sites to improve and redefine all assumptions considered in a complete LCA. Particularly if the evaluation is done prior the project on-site execution. The monitoring data would indicate important information such as energy consumption and fuel usage figures involved within the construction sector, instead of using figures coming from the literature available, allowing to calculate more accurate impacts for the A5 stage at early phases of all architectural projects.

- Energy simulation of buildings:

- Simplified LCA tools as basic decision-making project implementation

  These tools are the process with which all stakeholders of the construction sector base any decision regarding the changes made on a building project for a more sustainable outcome. Hence, they are becoming of great importance and will be further develop for a clearer and straightforward

This research has demonstrated a very clear and not very complex way to show that it is possible to achieve sustainable goals, including not only materials but also considering the complete project: transportation loads, the way that it's built on site (source of materials and components) and how to improve that process beyond the operational phase.

In this way we can achieve the sustainable targets and make the world a more sustainable space, not compromising future humans' generations activities. In summary, a better place to live on.

8.2.   Contribution to knowledge

When addressing the primary research question, this research presented the analysis of the Life Cycle Assessment of buildings, which is understood as a complex task within the construction sector. During this journey, this project has made some new contributions to this specific field presented below:

- The development of a new LCA calculation tool for domestic building with load-bearing wall and traditional construction techniques. Based on Matlab calculation engine capability using the calculation matrix defined on current international LCA regulations.

- The development of a new add-on calculation iteration including an innovative optimization process for insulation thickness and typology based on general and local building regulation.

- A targeted software's tool evaluation model gauging all information they could possibly consider. This also include a complete study of LCA tools classification, understanding the level of complexity and sophistication of each one analysed based on the user-level point of view.

- The demonstration of the potential of early design-stage LCA calculations and its possible repercussion to the environment in terms of carbon equivalent emissions and primary energy consumption.

- The development of an environmental dataset based on embodied energy (MJ) and carbon ($KgCO_2e$) by unit of area, instead of by mass of product and its potential contribution to user-friendly LCA calculations. It also includes an easy-to-update format.

- The development of a transport impact calculation tool and its potential implementation on current or new LCA calculations tools.

- The identification of major gaps within the environmental Lyfe Cycle Assessment of buildings and the possible solutions when addressing new scenarios for which no information is given.

- The assessment of three scenarios for a common UK building typology and its possible retrofit low energy solutions using the developed environmental dataset.

8.3.   Discussions and limitations

Future research topics and investigation lines could arise from the findings and knowledge contributions achieved in this thesis.

- **Environmental engagement**

One of them, possible the most important one, would be how to engage stakeholder for the use of LCA of buildings at the very early-design stages. This research has shown that user-friendly and little time-consuming LCA tools are achievable but a deeper commercial and implementation skills knowledge would be also beneficial.

Now-a-days LCA of buildings are used, mainly, within certification schemes of existing buildings which means that the improvement potential of those analysis is lost and only use for future recommendations. Only current real-estate investor, with a very sensitivity approach to carbon emissions, try to use LCA as their primary resource optimisation tool. Which sadly are a very rare case.

- **Database access**

One of the relevant parts of this study is the database itself. Environmental product declarations (EPD) have become more and more important as they try to compare different construction products with the same calculation methodology. Problem comes when different criteria has been considered or initial characteristics are no longer available on the market or the country of origin.

A thesis specific limitation was the access to these datasets of construction products due to the high licence fee that is needed for almost all of them. Hence, free-to-access environmental data was used, which come from empiric sources rather than literature and it is understood as valid. However, the tool is clearly limited by the age of those empiric processes considered and more recent to date is needed for new building evaluations in order to obtain results in accordance with the environmental values of the products currently used on new building projects.

It is known that EPD and other environmental information are private, hence, not always accessible. On the other hand, impacts indicated on those, and other datasets could be questioned prior using them as valid resources. Only those from expert organisations or externally verified should be used as a reference for accurate data.

Regarding this environmental information tightness, it could be thought that this sustainable field and tis world-wide solutions have been treated as a business resource rather than as a solution commitment to the pursue of a more sustainable world.

- **Net Zero Carbon and low energy buildings.**

New European policies has been stablished [17] pretending very low operational energy use since the very beginning, to achieve the net zero energy use by 2030 and embodied net zero completely by 2050 for a great variety of building typologies. [137]

Although energy impact could vary, they tend to be lower as green power supplies are developed. This is the case for some sustainable energy technologies such as hydraulic power plants. Electricity mix is however, lower and lower as transition from carbon and thermal generation gets real into other green electricity generation.

Given these circumstances, it is logical to think that this objective will be achieved with the current trend of industrial development in this regard.

However, this is not the expected outcome for embodied carbon which has also very restrictive targets for same periods [82]. In this case, LCA processes have much more power for changing since it is the only valid method to evaluate the state-of-art of the building stock as well as to demonstrate possible improvements and scenarios.

If net zero balance is desired, all stakeholders involved in the process should be aware of the importance of change needed. Not only. Operational consumption within each process but also at industry level with innovations on machinery, transport and processes. Otherwise, materials will always have a greater impact impossible to be avoided through the manufacturing and installation works in a short period of time.

- **Carbon compensation projects**

Nowadays, only carbon credits or compensation programs would allow for net zero achievement. With this regard, this is becoming a common practice between investors to obtain better carbon results with every construction development also influence by financial support offered by organizations and authorities when "green" projects are intended.

Consultants and other stakeholders can see how important carbon emissions have become not always only considering the environmental sensitivity of applicants but also business opportunities that may arise with these grants. Despite of the reason for which a better result is sought, deeper analysis of the building stock has already been considered, so that, the current sustainable strategy could work for developed countries.

- **On and off-site carbon strategies.**

On site works as well as off-site industrial manufacturing has always been considered antagonist process in terms of energy and resources efficiency. Since the second one could be seen as a process in which works are carried out in a controlled environment and accuracy could be great, on-site processes not always are as comfortable and precise as required.

On this matter, off-site industry has emerged as a possible real carbon saver solution as well as adding other improvements to the sector such as time-consuming avoidance and higher quality results. In addition, construction waste is reduced at the same time as circularity of materials is increased.

- **Circular economy**

Construction and demolition waste constitute a major concern within public and private policies since only this sector is responsible of a great number of activities involved in the production of a huge quantity of environmental impacts [REF?].

Regarding these impacts, efforts have been made to reduce, re-use and recycle this waste with the intention of not only reduce their impact but also to avoid the extensive use of natural resources of virgin materials. Current resources are already difficult to recover in a short space of time, which would make construction unsustainable with the forecast of existing global growth.

When abording the circularity of materials and resources, off-site construction, as well as reusing materials, are considered since the main principal is to avoid the new waste generation rather than recycling those materials since the second option would involve new processes. Hence, new impacts from transportation and waste treatment would result. The general lack of comparison between waste treatment routes and reusing or recycling materials are common within this sector, making difficult to decide the best possible solution for the lowest impact achievement.

8.4. Possible future work

Although the potential future work has been commented at every section as it has raised on this document, further complementary work is indicated as bellow:

8.4.1. Enlargement of environmental dataset

Adding more environmental data for many other products used in construction. They could vary from the foundation's options for other than common domestic buildings, until the great variety of external cladding finishes that are available on the market. Possible limitation to this section could be, as mentioned before, the lack of environmental data on new construction solutions and common figures.

8.4.2. Adding all sub-stages of the use phase of the building.

It is important to have a complete overall view of the life cycle of the building, also including some sub-stages that were not part of the scope of this thesis. This is the case of sub-stages such as B1 and B2, in which volatile components of paints and some other finishes and refrigerant annual leakage are involved.

8.4.3. Implementation of stand-alone version with user interface

Since the calculation tool, and all the matrix of scenarios and options, has been developed with Matlab software, which is the base for optimisation and computational programs, it becomes a real relatively easy option to possibly start either a stand-alone or commercial version of the tool.

8.4.4. Enlargement of the tool's options for non-domestic buildings

This method has been validated with domestic building cases, but it would be a great development to be able to evaluate other types of building and construction forms. They could be offices, educational, industrial, or even off-site constructions kits in order to evaluate how industrial innovations perform against conventional or "business-as-usual" processes.

8.4.5. Development of KPIs for "low-impacts" building elements

Based on the material used for the building elements, a list of the best possible solutions for each target of thermal comfort and location could be developed. This could be the start of a benchmark for either building elements, materials or building typologies.

8.5.   Summary

This project has investigated the general use of Life Cycle Assessment tools and environmental impacts, within the construction sector. It has also reviewed the current state-of-the-art of the construction sector and the available software tools for energy modelling and LCA, including certification schemes usually incorporated for rating buildings. All this research has given as a result several outputs, as indicated previously, being the core of them the achievement of a simplified but complete calculation tool for domestic buildings.

It has presented the results obtained from various case studies, implementing the international and European regulations with which LCA should be addressed. Results have been optimized to lower embodied carbon emissions and energy consumption. Those figures and procedures have been examined through a number of sensitivity analysis with the assumptions that are inherent to LCA of buildings within the scenarios stablished for the building stages of construction (A4-A5), use of the building (B4,B6) and end-of-use (C1-C4).

These results have shown the validity of the proposed tool and how the project has successfully completed the objectives set out since the beginning of the thesis and has contributed to knowledge in several useful areas, which can inform the future development of the LCA of buildings and housing projects.

9

CHAPTER 9: REFERENCES

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A

APPENDIX A: UNIT CONVERSION AND IMPACT CALCULATIONS

1. Initial unit's conversion

As explained in unit "5.4.1.1. Indicator's unit conversion" indicators are often given by unit of mass. This means it´s almost impossible to applied them directly to building's measurements and sum them up for the global figure. Hence a conversion is needed getting from "Indicator/Kg" to "Indicator/m^2", which is a measure capable to be applied to buildings. It is only needed the density and thickness that the material or element will have within the building using the following formula:

$$Indicator_{ENV} \cdot d \cdot Th = Indicator_{SLCA} = \frac{Indicator}{Kg} \cdot \frac{Kg}{m^3} \cdot m = \frac{Indicator}{m^2}$$

Eq. 2 (Data base

This will be explained using a conversion example with the calculation of the environmental impact of a 1m^2 piece of wall made only of cement mortar. The thickness of the wall would be 0.1025m and the density of this mortar is 1,900kg/m^3.

Cement mortar has an Embodied Energy (EE) of 0.97 MJ/Kg and an Embodied Carbon (EC) equal to 0.156 KgCO$_2$e according to the database used [138]:

$$d = 1,900 \ Kg/m^3; \ Th = 0.01; \ EE_{ENV} = 0.97 \ MJ/Kg; \ EC_{ENV} = 0.156 \ KgCO_2e$$

Following (Eq. 2):

$$\frac{Indicator}{Kg} \cdot \frac{Kg}{m^3} \cdot m = \frac{Indicator}{m^2}$$

$$EE: 0.97 \cdot 1,900 \cdot 0.1025 = 188.90 \ MJ/m^2$$

$$EC: 0.156 \cdot 1,900 \cdot 0.1025 = 30.38 \ KgCO_2e/m^2$$

If we imagine a wall 0.1025m thick, made just of cement mortar, would have an embodied energy of 188.90 MJ and an embodied carbon of 30.38 KgCO$_2$e per square metre.

Table A.1: Environmental unit's conversion

Material	Density	Thickness	EE		EC	
Units	Kg/m^3	m	MJ/Kg	MJ/m^2	KgCO$_2$e/Kg	KgCO$_2$e/m^2
Mortar	1,900	0.1025	0.97	18.430	0.156	2.964

These are the environmental loads for 1m^2 of mortar 0.01m thick. The same method is followed for all other materials used in this project.

2. Compound materials calculation

This calculation will be explained with a single brick wall example. The same process is used for others composite materials involved in this research.

It is calculated that for 1 sqm of single brick wall 60 bricks are needed with 10mm of mortar thickness in between. This amount of brick accounts for the 84% of the area. The resting area, 16%, is dedicated to mortar. See picture for graphic information

Single Brick wall example:

1 m^2 of single brick wall (Th=0.1025m)

Brick's area = 84% (0.84m^2)

Mortar's area = 16% (0.16m^2)
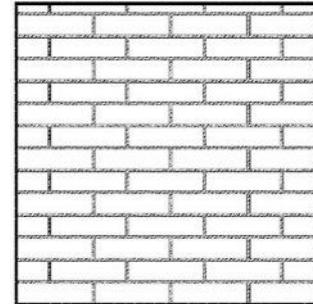
Figure A.1: Single Brick wall composite material

UK Brick calculation:

$d = 1,600 Kg/m^3; Th = 0.1025; EE_{ENV} = 3\ MJ/Kg; EC_{ENV} = 0.24\ KgCO_2e$

Calculations with bricks could be a bit different because the environmental data is given by unit of weight and it is known that a UK generic brick averages 2.3Kg of weight. It is counted that 60 bricks are needed for the area involved giving a total of 138Kg. Then calculation could be just multiplying the impact of one Kg times 138, giving the following figures:

6. EE = 414 MJ/m^2 of wall
7. EC = 33.12 KgCO$_2$e/m^2 of wall.

Using formula (Eq. 2), brick's impact could also be done using density (1,600 Kg/m^3) and thickness (0.1025 m) and multiplying the resulting figure by the percentage of area that the brick represents in 1m2 of wall. Following this method, the EE due to bricks of 1m^2 wall would be the following:

$$Indicator_{ENV} \cdot d \cdot Th \cdot \% = Indicator_{SLCA}\ of\ element$$

Eq. 3 (Env. Impact ~~of~~

$EE: 3 \cdot 1,600 \cdot 0.1025 \cdot 0.84\ = 413.24\ MJ/m^2\ of\ wall$

$EC: 0.24 \cdot 1,600 \cdot 0.1025 \cdot 0.16 = 33.02\ KgCO_2e/m^2\ of\ wall$

The resulting figures this way are the same as if using the method explained before.

Mortar calculation:

The mortar impacts are then calculated using in order to get the figure by sqm. In this case the area of 1sqm corresponding to mortar is $0,16m^2$. Following (Eq. 3) for a wall $0,1025m$ thick impacts are 188.90MJ and $30.38KgCO_2e$ per square metre. Multiplying these figures by 16% of area corresponding to the mortar in 1m2 of wall the following results are obtained:

EE ($1m^2$ of wall): 188.90*0.16 = 30.50 MJ/m^2 of wall

EC ($1m^2$ of wall): 30.38*0.16 = 4.90 $KgCO_2e/m^2$ of wall

Now both figures, bricks and mortar, would need to be added in order to get the final figure for the impact of unit of measure of single brick wall (102.5mm). This addition could be summarised in the following table:

Table A.2: Environmental impact of 1 square metre of single brick wall

Material	Density	Percent	Embodied Energy			Embodied Carbon		
	(d)	(%)	MJ/Kg	MJ/m^2	MJ/m2 wall	$KgCO_2e/Kg$	$KgCO_2e/m^2$	$KgCO_2e/m^2wall$
UK Brick	1,600	84	3	492.00	414.00	0.24	39.36	33.12
Mortar	1,900	16	0.97	188.90	30.51	0.156	30.38	4.91
			Subtotals Energy:		**444.51**		**Subtotal Carbon:**	**38.03**

This example explains how all compound materials are calculated. Such as Light metal studs walls, or timber studs walls.

3. Timber products

Environmental data for timber products is taking into consideration the worst possible manufacturing scenario. The proposed database contains EE and EC from fossil fuels and from the biomass. This is assuming that the biomass is not carbon neutral. This assumption is possible when considering timber products from non-sustainably managed forests. When considering all or some timber products from sustainably managed forest then the environmental impact due to the biomass could be avoided as it would be considering those impacts as carbon neutral.

In addition, none of the environmental data, within the simplified methodology, related to timber products does not include the effects of carbon sequestration during the growing of the trees process or the biogenic carbon storage within the timber itself. Inclusion or exclusion of sequestered carbon is a very complex process which is out of the scope of this research project. However, the database is made in such a way that when accurate data regarding these processes became available and easier to quantify, it could be easily updatable.

a) Timber I-joist @ 400mm. Made of plywood and OSB:

Timber I-joists @400mm. They are made of 45x45 plywood base and head with a 9mm OSB sheet aligned vertical. A Total height is considered at 250mm. Separation between them is 400mm.

For this calculation, the combination of the three different elements is considered for 1m joist. Volumes of timber are calculated and the impacts of each one using I.C.E. 2.0 data "indicator" by Kg. Know the density, the volume, and this indicator we could have the total amount of MJ and $KgCO_2e$ respectively for 1m of timber I-joist.

In order to have the impact by sqm, the sum of those total impacts is multiplied by 2.5, which is the number of I-joist located in one square metre. Or, in other words, if area of influence of one joist ($0.4m^2$) would have been calculated and the multiplied the times needed for one sqm (2.5 times).

Table A.3: environmental impact of 1 square metre of timber I-joist @400mm

Element	Density	Volume	Embodied Energy			Embodied Carbon		
	(d)	(m^3)	MJ/Kg	MJ	MJ/m2	$KgCO_2e$/Kg	$KgCO_2e$	$KgCO_2e/m^2$
Head flange	540	0.002115	9,5	10.85	27.12	0.65	0.74	1.85
Web	640	0.001440	15	13.82	34.56	1.00	0.92	2.30
Bottom flange	540	0.002115	9,5	10.85	27.12	0.65	0.74	1.85
			Subtotals Energy:		88.80	**Subtotal Carbon:**		6.01

Same process will be used for other I-joist and gaps between them in order to have more options in the future.

4. Concrete product

For concrete materials we can separate in-situ, precast concrete and concrete blocks. A complete list of material's indicators could be found on "appendix A. Concrete".

According with the ICE dataset of products, concrete elements impacts will vary depending on the quantity (mass) of steel used as reinforcement. The following assumptions are taken into consideration for this PhD:

a) In-situ reinforced concrete

When talking about in-situ reinforced concrete products the environmental data used has different figures depending on the compressive strength designation and quantity of steel used within the concrete to reinforce it. When same thickness is calculated.

Different compressive strength concrete could be found in this database. However, it is assumed that, for calculation procedure, all concrete will have 100Kg of steel per cubic metre is used. Other concrete specification could be available from the future work.

b) Pre-cast concrete

It is assumed that all pre-cast concrete elements used for the tool will be 20/25Mpa of compressive strength designation with 80Kg of steel per cubic metre is used. Other pre-cast concrete specification could be available from the future work.

a) Concrete blocks

It is assumed that all light pre-cast concrete blocks used for the assessments will be 8/10Mpa of compressive strength designation while the dense pre-cast concrete blocks will have 10Mpa of compressive strength designation.

A complete list of different strength concrete options, with 100Kg of rebar by m3, and concrete blocks is represented as follows:

Table A.4: environmental loads of concrete products

Concrete	Rebar	In-Situ		Pre-Cast	
Compressive Strength	**Kg**	**MJ/Kg**	**KgCO$_2$e/Kg**	**MJ /Kg**	**KgCO$_2$e/Kg**
General Concrete	100	1.79	0.184	2.24	0.213
16/20MPa	100	1.74	0.177	2.19	0.206
20/25MPa	80	1.572	0.1686	2.022	0.1976
20/25MPa	100	1.78	0.184	2.23	0.213
25/30MPa	100	1.82	0.19	2.27	0.219
28/35MPa	100	1.86	0.197	2.31	0.226
32/40MPa	110	2.024	0.2167	2.474	0.2457
40/50MPa	100	2.04	0.228	2.49	0.257
Block - 8 MPa	-	-	-	0.59	0.063
Block - 10 MPa	-	-	-	0.67	0.078
Block - 12 MPa	-	-	-	0.72	0.088
Block - 13 MPa	-	-	-	0.83	0.107

5. Windows and door impact

In order to properly address the environmental impact of windows and doors, within the manufacturing stage, the question raised was to have it by unit of area or by units of products, bearing in mind that the second option would always need a secondary or third conversion.

It has been analysed how different would it be to consider impacts of manufacturing stage by sqm or by number of units. So that, impact could be considered on the most appropriate way. This example is extensive to all other windows and all doors.

Environmental impact, following the ICE 3.0 database per unit of single glazed and timber framed windows of 1.2 by 1.2m (1.44m^2), for manufacturing stage, are 230 MJ and 12 KgCO$_2$e, for each window unit. This would result on a unitary glazed area impact of 159.72 MJ and 8.33 KgCO$_2$e by sqm.

Following calculations for the "BRE" case study, comparison between these two options are applied as follows:

There are 34 windows within this building:

- 22 units of 150cm x 95cm. Having a total glazed area of 31,35m2.
- 12 units of 150cm x 77cm. Having a total glazed area of 13,83m2.

Environmental impact would result, by unit of window impact, on 7820 MJ and 408 KgCO$_2$e for sub-stages A1 to A3. Having in mind the 34 units of the project.

However, if the unit of glazed area impact is applied, the result would be 7216.15 MJ and 376.35 KgCO$_2$e. having applied the 45,18m2 of glazed are of the project.

Hence, making calculation by units of 1,2x1,2m an increment of approximately 8% of impacts are achieved. This is because dimensions of actual windows are slightly smaller than the unit studied by the database.

Calculation should be done by glazed area for accurate results and that unitary impact would be included on the current tool's database for calculation purposes of each type of window indicated on Chapter 5.

6. Transport loads

Defining the type of vehicle used for the transport of materials, its fuel consumption and its utilisation usage percentage, it is possible to know how many litres of fuel are consumed for each amount of material. UK DEFRA and current European standard quantify environmental figures in energy by litre or tonne of fuel. This calculation tool focuses in petrol and diesel as main fuel used for road transport. Distances units are miles, but conversion to km could be done directly.

From UK government freighting good vehicles information, energy fuel usage impact gives a unit of MJ for litre used. However, following the current standards (REF EN-16258), for environmental impacts from fuel consumption, these could be achieved from two different assumption:

8. Tank-To-Wheel (TTW) which includes impacts produced just for the usage within the vehicle itself. Assuming that manufacturing and transport impact from getting the fuel to the gas station is already included in the conversion factor for fuel consumption to energy unit.
9. Wheel-To-Wheel (WTW) which includes impacts produced from the manufacturing and transport of that fuel to the gas station. Assuming conversion factor from fuel consumption to energy unit does not include those figures.

For embodied energy calculations within this method, energy impact from fuel is obtained from government figures, that are assumed to be TTW and very similar to the TTW figures from EN 16258 is assumed from government energy impacts from fuel, which are very similar to been used. They are summarised within the following table:

Table A.5: energy impact from fuel usage – tool conversion

Tool conversion from fuel diesel and petrol					BS EN 16258-2012
Type	L/tonne	Kg/L	GJ/tonne	MJ/L	MJ/L
Diesel	1,192.00	0.83893	42.91	35.99	**35.9**
Petrol	1,368.00	0.73099	44.78	32.73	**32.7**

Fuel consumption of each vehicle is summarised on the following table:

Table A.6: Average fuel freight good vehicles

Vehicle	Mpg	L/km
Rigid (>3.5-7.5 tonnes)	13.6	0.538
Rigid (>7.5-14 tonnes)	11.3	0.6475
Rigid (>14-17 tonnes)	9.8	0.7466
Rigid (>17-25 tonnes)	9.4	0.7783
Rigid (>25 tonnes)	6.5	1.1256
All Rigids (average)	**8.9**	**0.822**
Artics (>3.5t-33t)	9.0	0.8129
Artics (>33t)	7.8	0.938
All Artics (average)	**7.9**	**0.9261**
Van Class I (up to 1.305 t)	32.08	0.228
Van Class II (1.305 to 1.74 t)	22.86	0.32
Van Class III (1.74 to 3.5 t)	22.86	0.32

For embodied carbon calculations from HGV, the proposed tool uses the table below:

Table A.7: Average CO$_2$ emissions of Vans

Type \ Load	Unit	Diesel kg CO$_2$e	Petrol kg CO$_2$e	Unknown kg CO$_2$e
Class I (up to 1.305 t)	km	0.144477	0.190714	-
	tonne.km	0.61214	0.810251	-
Class II (1.305 to 1.74 t)	km	0.228331	0.2124	-
	tonne.km	0.633423	0.806109	-
Class III (1.74 to 3.5 t)	km	0.267749	0.257481	-
	tonne.km	0.502728	0.483084	-
Average (up to 3.5 t)	**km**	**0.24999**	**0.20994**	**0.24831**
	tonne.km	**0.529972**	**0.683723**	**0.538072**

Following figures are the complete tables of figures from DEFRA UK goverment [103]:

Table A.8: Average CO$_2$ emissions of Heavy Good Vehicles (HGV)

Type \ Load	Unit	0% Laden kg CO$_2$e	50% Laden kg CO$_2$e	100% Laden kg CO$_2$e	Average laden kg CO$_2$e
Rigid (>3.5 - 7.5 tonnes)	km	0.524679	0.569809	0.614939	0.565299
	tonne.km	-	0.50559	0.27281	0.55731
Rigid (>7.5 -17 tonnes)	km	0.623123	0.711143	0.799163	0.691783
	tonne.km	-	0.26929	0.15131	0.36024
Rigid (>17 - 25 tonnes)	km	0.790204	0.961464	1.132724	0.998744
	tonne.km	-	0.23057	0.13582	0.17398
All rigids (average)	**km**	**0.66567**	**0.80995**	**0.95423**	**0.83242**
	tonne.km	**-**	**0.28984**	**0.17073**	**0.21249**
Articulated (>3.5 - 33t)	km	0.685856	0.855206	1.024556	0.841666
	tonne.km	-	0.14278	0.08553	0.1343
Articulated (>33t)	km	0.692514	0.920054	1.147594	0.983764
	tonne.km	-	0.09995	0.06234	0.08164
All Artics (average)	**km**	**0.75194**	**0.93742**	**1.1229**	**0.9967**
	tonne.km	**-**	**0.10441**	**0.06254**	**0.0855**

For this proposed method, the "trade point" to "building site" distance is, by default, fixed in 50miles (80km) for simplicity. This is accepted for industry experts. However, if more detailed transport routes are known they could be specified and include in the calculation. With all the data gathered and following equations 3, 4 and 5 we would obtain the following results for energy and carbon impacts. We´ll explain these figures with an example for the following given data:

Data for example:

Distance: 80km (50miles)

Vehicle: Rigid (>3.5 – 7.5 tonnes) 50% loaded

> *Fuel consumption: 0.538 L/km*

> *Load transported: 7.5 x 0.5 = 3.75 tonnes*

> *Carbon emissions when 50% loaded: 0.50559 KgCO$_2$e/km·tonne*

Material: plasterboard

> *Density: 900 Kg/m³*

> *Thickness: 0.0125m*

Following equation 3 for energy impacts:

$$\frac{EE_{fuel} \cdot consumption \cdot distance}{load\ mass} = \frac{35.99 \cdot 0.538 \cdot 80}{3.75} = 413.16 \frac{MJ}{tonne}\ (I)$$

Following equation 4 for carbon emissions impacts:

$$\frac{EC_{fuel} \cdot distance}{load\ mass} = \frac{0.50559 \cdot 80}{3.75} = 40.44 \frac{KgCO_2e}{tonne}\ (II)$$

These figures are utterly independent from the material transported. Know, in order to get those indicators by unit of area in which the material transported will be used within the building, we use equation 5 for each indicator achieved:

$$(I)\ \frac{Indicator}{load\ mass} \cdot d \cdot Th = \frac{413.16}{1,000\ (Kg)} \cdot 900 \cdot 0.0125 = 4.64 \frac{MJ}{m^2}\ of\ plasterboard$$

$$(II)\ \frac{Indicator}{load\ mass} \cdot d \cdot Th = \frac{40.44}{1,000\ (Kg)} \cdot 900 \cdot 0.0125 = 0.45 \frac{KgCO_2e}{m^2}\ of\ plasterboard$$

The proposed tool would calculate with this method all transport impacts. When calculating transport impact from vans, the method would be the same but just selecting the figure depending on the fuel selected and avoiding the percentage of load.

B

APPENDIX B: MATERIAL DATABASE

I.   Concrete products considerations

Table B.1: environmental loads of concrete products

Concrete	Rebar	In-Situ		Pre-Cast	
Compressive Strength	**Kg**	**MJ/Kg**	**KgCO$_2$e/Kg**	**MJ /Kg**	**KgCO$_2$e/Kg**
General Concrete	100	1.79	0.18	2.24	0.21
16/20MPa	100	1.74	0.17	2.19	0.20
20/25MPa	80	1.572	0.16	2.022	0.19
20/25MPa	100	1.78	0.18	2.23	0.21
25/30MPa	100	1.82	0.19	2.27	0.21
28/35MPa	100	1.86	0.19	2.31	0.22
32/40MPa	110	2.024	0.21	2.474	0.24
40/50MPa	100	2.04	0.22	2.49	0.25
Block - 8 MPa	-	-	-	0.59	0.06
Block - 10 MPa	-	-	-	0.67	0.07
Block - 12 MPa	-	-	-	0.72	0.08
Block - 13 MPa	-	-	-	0.83	0.10

II.　　　　Material database

Table B.2: material database for cements, clay & concrete products

FAMILY	CODE	NAME	Width (m)	Density (Kg/m3)	RqSL (Years)	Site waste (%)	% sent to: Landfill	Incineration	Recycling	A1-A3 Aggregated Impact KgCO2e/m2	MJ/m2
CEMENT & MORTARS	CEM-1	Cement CEM I (Portland 94% Clinker)	0.01	1,650.00	60.00	5.00	90.00	1.00	9.00	15.68	90.75
	CEM-2	General Cement	0.02	1,650.00	60.00	5.00	90.00	1.00	9.00	18.32	111.62
	MOR-1	Cement Dry Mortar (1:5)	0.02	1,900.00	60.00		90.00	1.00	9.00	4.45	27.65
	MOR-2	Cement Mortar (1:1:6)	0.01	1,800.00	60.00	5.00	90.00	1.00	9.00	4.98	25.74
	MOR-3	General Cement Plaster	0.01	1,400.00	60.00	5.00	90.00	1.00	9.00	1.82	25.20
	MOR-4	Cement Mortar in single brick walls	0.10	1,900.00	30.00	5.00	90.00	1.00	9.00	4.91	30.51
	MOR-5	Cement Mortar in double brick walls	0.22	1,900.00	30.00	5.00	90.00	1.00	9.00	10.29	63.99
	MOR-6	Dot and Dab	0.01	1,900.00	30.00	5.00	90.00	1.00	9.00	0.48	2.98
CLAY & CERAMICS	CLAY-1	UK Single Clay Brick Wall	0.10	1,900.00	60.00	5.00	50.00	0.00	50.00	38.03	444.51
	CLAY-2	UK Double Clay Brick Wall	0.22	1,900.00	60.00	5.00	50.00	0.00	50.00	79.02	907.45
	CLAY-3	Clay Brick Slip	0.01	1,700.00	60.00	7.50	50.00	0.00	50.00	4.45	55.59
	CLAY-4	General Clay Tile	0.01	1,900.00	60.00	7.50	50.00	0.00	50.00	10.94	148.20
	CLAY-5	Foundations UK Single Clay Brick Wall	0.10	1,900.00	60.00	5.00	50.00	0.00	50.00	13.86	161.99
	CLAY-6	Foundations UK Double Clay Brick Wall	0.22	1,900.00	60.00	5.00	50.00	0.00	50.00	19.24	224.30
	CLAY-7	Spanish Brick Wall (d=0,24m)	0.24	1,705.00	60.00	5.00	50.00	0.00	50.00	59.24	626.17
	CLAY-8	Spanish Brick Wall (d=0,365m)	0.37	1,705.00	60.00	5.00	50.00	0.00	50.00	86.49	914.21
	CLAY-9	Spanish Brick Wall (d=0,49m)	0.49	1,705.00	60.00	5.00	50.00	0.00	50.00	102.62	1,152.54
CONCRETE	CON-1	In-situ Concrete 20/25 Raft Foundation (d=50/30cm)	0.50	2,300.00	60.00	5.00	50.00	0.00	50.00	96.07	951.55
	CON-2	In-situ Concrete 20/25 Strip Foundation (60cmx40cm)	0.40	2,300.00	60.00	5.00	50.00	0.00	50.00	74.03	716.15
	CON-3	Pre-cast concrete 20/25 (thck=20cm)	0.20	2,300.00	60.00	5.00	50.00	0.00	50.00	77.56	929.20
	CON-4	Dense Concrete block wall (d=10cm)	0.10	1,950.00	60.00	5.00	50.00	0.00	50.00	20.27	148.54
	CON-5	Dense Concrete block wall (d=20cm)	0.20	1,950.00	60.00	5.00	50.00	0.00	50.00	40.54	297.07
	CON-6	Dens concrete dintel (10x300x150mm)	0.06	1,950.00	60.00	5.00	50.00	0.00	50.00	6.47	11.87
	CON-7_A	In-situ Concrete 20/25 RAVENSCRAIG Strips Found	0.18	2,300.00	60.00	5.00	50.00	0.00	50.00	74.03	716.15
	CON-7_B	In-situ Concrete 20/25 RAVENSCRAIG Raft Founda	0.40	2,300.00	60.00	5.00	50.00	0.00	50.00	169.51	1,639.82
	CON-8	In-situ Concrete 20/25 YOKER Strips Foundation (6	0.25	2,300.00	60.00	5.00	50.00	0.00	50.00	121.86	1,360.80
	CON-9	In-situ Concrete 20/25 YOKER Slab (d=175mm)	0.18	2,300.00	60.00	5.00	50.00	0.00	50.00	74.06	716.45
	CON-10	Concrete screed (d=50mm)	0.05	2,300.00	60.00	5.00	50.00	0.00	50.00	10.50	73.50
	CON-11	Concrete screed (d=70mm)	0.07	2,300.00	60.00	5.00	50.00	0.00	50.00	14.70	102.90
	CON-12	Concrete YOKER piles (diam=750mm)	2.60	2,300.00	80.00	5.00	50.00	0.00	50.00	1,103.02	10,670.52
	CON-13	Light Concrete block wall (d=10cm)	0.10	1,450.00	60.00	5.00	50.00	0.00	50.00	15.43	112.25
	CON-14	Light Concrete block wall (d=20cm)	0.20	1,450.00	60.00	5.00	50.00	0.00	50.00	30.86	224.50
	CON-14	Light Concrete block wall (d=30cm)	0.30	1,450.00	60.00	5.00	50.00	0.00	50.00	46.28	336.75
	CON-15	Light Concrete block wall (d=35cm)	0.35	1,450.00	60.00	5.00	50.00	0.00	50.00	54.00	392.88
	CON-16	Light Concrete block wall (d=40cm)	0.40	1,450.00	60.00	5.00	50.00	0.00	50.00	61.71	449.00
	CON-17	In-situ concrete 20/25MPa wall (d=25cm)	0.25	1,950.00	60.00	5.00	50.00	0.00	50.00	40.54	297.07

Table B.3: material database for insulations & gypsum products

FAMILY	CODE	NAME	Width (m)	Density (Kg/m3)	RqSL (Years)	Site waste (%)	% sent to: Landfill	Incineration	Recycling	A1-A3 Aggregated Impact KgCO2e/m2	MJ/m2
INSULATION	INS-1A	Mineral Wool Insulation 25mm	0.10	105.00	30.00	10.00	90.00	0.00	10.00	3.36	43.58
	INS-1B	Mineral Wool Insulation 50mm	0.05	105.00	30.00	10.00	90.00	0.00	10.00	6.72	87.15
	INS-1C	Mineral Wool Insulation 100mm	0.10	105.00	30.00	10.00	90.00	0.00	10.00	13.44	174.30
	INS-1D	Mineral Wool Insulation 150mm	0.15	105.00	30.00	10.00	90.00	0.00	10.00	20.16	261.45
	INS-1E	Mineral Wool Insulation 200mm	0.20	105.00	30.00	10.00	90.00	0.00	10.00	26.88	348.60
	INS-2A	Woodwool board Insulation 100mm	0.10	173.00	30.00	8.00	90.00	0.00	10.00	16.95	168.84
	INS-2B	Woodwool board Insulation 150mm	0.15	173.00	30.00	8.00	90.00	0.00	10.00	25.43	280.26
	INS-2C	Woodwool board Insulation 200mm	0.20	173.00	30.00	8.00	90.00	0.00	10.00	33.90	373.68
	INS-3A	Rock Wool Insulation 100mm	0.10	23.00	30.00	8.00	90.00	0.00	10.00	4.37	65.52
	INS-3B	Rock Wool Insulation 150mm	0.15	23.00	30.00	8.00	90.00	0.00	10.00	6.55	98.28
	INS-3C	Rock Wool Insulation 200mm	0.20	23.00	30.00	8.00	90.00	0.00	10.00	7.73	131.04
	INS-4A	Fibreglass Glasswool Insulation 100mm	0.10	10.50	30.00	8.00	90.00	0.00	10.00	1.41	29.40
	INS-4B	Fibreglass Glasswool Insulation 150mm	0.15	10.50	30.00	8.00	90.00	0.00	10.00	2.12	44.10
	INS-4C	Fibreglass Glasswool Insulation 200mm	0.20	10.50	30.00	8.00	90.00	0.00	10.00	2.83	58.80
	INS-5D	Expanded Polystyrene Insulation 50mm	0.05	105.00	30.00	10.00	90.00	0.00	10.00	7.40	199.35
	INS-5G	Expanded Polystyrene Insulation 80mm	0.08	105.00	30.00	10.00	90.00	0.00	10.00	11.84	318.96
	INS-5A	Expanded Polystyrene Insulation 100mm	0.10	105.00	30.00	10.00	90.00	0.00	10.00	14.80	398.70
	INS-5B	Expanded Polystyrene Insulation 150mm	0.15	105.00	30.00	10.00	90.00	0.00	10.00	22.20	598.00
	INS-5F	Expanded Polystyrene Insulation 170mm	0.17	105.00	30.00	10.00	90.00	0.00	10.00	25.16	677.79
	INS-5C	Expanded Polystyrene Insulation 200mm	0.20	105.00	30.00	10.00	90.00	0.00	10.00	29.61	797.40
	INS-5E	Expanded Polystyrene Insulation YOKER foundatio	0.15	105.00	30.00	10.00	90.00	0.00	10.00	14.69	304.70
GYPSUM	PLAST-1	General Gypsum/Cement Plaster	0.01	1120.00	15.00	5.00	90.00	9.00	1.00	1.45	20.16
	PLAST-2	Lime Plaster (1:1:6)	0.01	1400.00	15.00	5.00	90.00	9.00	1.00	2.98	15.40
	PLAST-3	Single Plasterboard	0.01	900.00	30.00	8.00	98.00	0.00	2.00	4.38	75.94
	PLAST-4	Double Plasterboard	0.03	900.00	30.00	8.00	98.00	0.00	2.00	8.76	151.87
	PLAST-5	Light Metal Studs C shape 70x50mm @600	0.05	900.00	30.00	10.00	10.00	0.00	90.00	0.63	7.46
	PLAST-6	Light Metal Studs C shape 50x50mm @600	0.05	900.00	30.00	10.00	10.00	0.00	90.00	0.54	6.36

Table B.4: material database for timber, finishes, windows & doors products

FAMILY	CODE	NAME	Width (m)	Density (Kg/m3)	RqSL (Years)	Site waste (%)	% sent to: Landfill	Incineration	Recycling	A1-A3 Aggregated Impact KgCO2e/m2	MJ/m2
TIMBER	TIM-1	Timber Particle Boards	0.02	800.00	30.00	10.00	10.00	85.00	5.00	19.18	281.60
	TIM-2	Glue Laminated Timber (GLT)	0.40	460.00	60.00	3.00	10.00	85.00	5.00	6.62	110.40
	TIM-3	Laminated Veneer Lumber (LVL)	0.10	540.00	60.00	10.00	10.00	85.00	5.00	1.75	25.65
	TIM-4	Oriented Strand Board (OSB)	0.09	640.00	30.00	10.00	10.00	85.00	5.00	5.76	86.40
	TIM-5	Timber Plywood	0.01	540.00	60.00	10.00	10.00	85.00	5.00	7.42	101.25
	TIM-6	Timber I-Joists @ 600mm	0.01	540.00	60.00	2.00	10.00	85.00	5.00	59.21	4.01
	TIM-7	Timber I-Joists @ 400mm	0.01	540.00	60.00	2.00	10.00	85.00	5.00	88.81	6.01
	TIM-8	Sawn Timber Roof Truss 30°	0.01	540.00	60.00	2.00	10.00	85.00	5.00	42.53	621.60
	TIM-9	Sawn Softwood for doors	0.01	510.00	60.00	5.00	10.00	85.00	5.00	42.44	621.60
	TIM-10	Cross Laminated Timber (CLT) walls	0.12	460.00	60.00	3.00	10.00	85.00	5.00	46.42	640.32
	TIM-11	Cross Laminated Timber (CLT) floors	0.12	460.00	60.00	3.00	10.00	85.00	5.00	47.62	656.88
	TIM-12	Softwood battens 50x50mm	0.05	460.00	60.00	10.00	10.00	85.00	5.00	1.53	21.25
	TIM-13	Softwood battens 70x50mm	0.07	460.00	60.00	10.00	10.00	85.00	5.00	2.14	29.75
	TIM-14	Timber Studs 150x50mm	0.15	460.00	60.00	10.00	10.00	85.00	5.00	4.59	63.75
	TIM-15	HPL panel 8mm	0.01	460.00	60.00	5.00	10.00	85.00	5.00	37.40	804.00
FINISHES	FIN-1	General paint Single Coat	0.00	800.00	30.00	10.00	95.00	5.00	0.00	0.44	10.51
	FIN-2	General paint Double Coat	0.00	800.00	30.00	10.00	95.00	5.00	0.00	0.87	21.02
	FIN-3	Waterborne Paint	0.00	800.00	30.00	10.00	95.00	5.00	0.00	0.38	8.86
	FIN-4	Solventborne paint	0.00	800.00	30.00	10.00	95.00	5.00	0.00	0.56	15.56
	FIN-5	General Carpet	0.02	800.00	30.00	5.00	90.00	10.00	0.00	187.00	9.80
	FIN-6	General Wallpaper (350g/m2)	0.00	800.00	30.00	5.00	85.00	10.00	5.00	0.29	5.46
	FIN-7	General Vinyl Flooring	0.00	1200.00	30.00	5.00	82.00	0.00	8.00	13.74	393.84
	FIN-8	Slate Tiles	0.01	1600.00	30.00	5.00	90.00	0.00	10.00	43.97	1260.30
	FIN-9	Slate Tiless for Roof 30°	0.01	1600.00	30.00	5.00	90.00	0.00	10.00	55.40	1587.98
	FIN-10	Vinyl brick slips	0.01	1200.00	30.00	5.00	82.00	0.00	8.00	1260.29	46.97
WINDOWS	WIN-1	Window Single Glazed-TIMBER	0.15	800.00	30.00	2.50	0.00	0.00	100.00	8.33	159.72
	WIN-2	Window Double Glazed-ALUM	0.15	460.00	30.00	2.50	0.00	0.00	100.00	52.08	1013.89
	WIN-3	Window Double Glazed-PVC	0.15	540.00	30.00	2.50	0.00	0.00	100.00	87.50	1715.28
	WIN-4	Window Double Glazed-TIMBER	0.15	540.00	30.00	2.50	0.00	0.00	100.00	17.36	340.28
DOORS	INT.DO-1	Timber Framed Interior Door	0.05	540.00	40.00	2.50	0.00	0.00	100.00	3.79	47.57
	INT.DO-2	PVC Framed Interior Door	0.05	540.00	40.00	2.50	0.00	0.00	100.00	9.71	117.03
	EXT.DO-2	Timber Framed Exterior Door	0.05	540.00	40.00	2.50	0.00	0.00	100.00	3.79	47.57
	EXT.DO-1	PVC Framed Exterior Door	0.05	540.00	60.00	2.50	0.00	0.00	100.00	9.71	117.03

Table B.5: material database for other products

FAMILY	CODE	NAME	Width (m)	Density (Kg/m3)	RqSL (Years)	Site waste (%)	% sent to: Landfill	Incineration	Recycling	A1-A3 Aggregated Impact KgCO2e/m2	MJ/m2
	OTHER-1	Dump Membrane	0.00	1120.00	60.00	15.00	90.00	10.00	0.00	4.03	450.24
	OTHER-2	General Soil	0.50	1450.00	60.00	15.00	30.00	0.00	70.00	17.52	328.50
	OTHER-3	General Sand	0.01	0.03	60.00	15.00	30.00	0.00	70.00	0.57	0.90
	OTHER-4	General Rubber, hardwood & Cement Mixture	0.01	1200.00	60.00	15.00	90.00	10.00	0.00	1365.00	42.75
	OTHER-5	General Aggregate	0.50	2240.00	60.00	15.00	30.00	0.00	70.00	5.82	92.96
OTHER	OTHER-6	Air Gap	0.00	0.00	60.00	0.00	0.00	0.00	0.00	0.00	0.00
	OTHER-7	Gravel for Strip Foundations	0.50	2240.00	60.00	15.00	30.00	0.00	70.00	3.53	56.36
	OTHER-8	Gravel for YOKER Strip Foundations	0.25	2240.00	60.00	15.00	30.00	0.00	70.00	2.01	32.11
	OTHER-9	Glue for vinyl finish	0.00	1200.00	60.00	10.00	30.00	0.00	70.00	7.15	211.20
	OTHER-10	Stabilised soil wall d=0,24m	0.24	1790.00	60.00	5.00	50.00	0.00	50.00	23.06	327.64
	OTHER-11	Stabilised soil wall d=0,30m	0.30	1790.00	60.00	5.00	50.00	0.00	50.00	30.02	409.55
	OTHER-12	Stabilised soil wall d=0,36m	0.36	1790.00	60.00	5.00	50.00	0.00	50.00	36.04	511.67
	OTHER-13	Stabilised soil wall d=0,42m	0.42	1790.00	60.00	5.00	50.00	0.00	50.00	42.03	596.95

III.   Transport loads and impacts

Table B.6: transport impacts

VEHICLE	TYPE	Consumption (L/km)	Emissions (KgCO₂e/t*km)	Load (%)	Load (Tonnes)	Impact values (80km) KgCO₂e/t	MJ/t	Impact values (160km) KgCO₂e/t	MJ/t
Heavy Good Vehicles	Rigid (>3,5-7,5t)	0.54	0.51	50.00	3.75	20.22	1,541.79	40.45	3,083.57
			0.27	100.00	7.50	21.82	1,541.79	43.65	3,083.57
	Rigid (>7,5-14t)	0.65	0.27	50.00	7.00	10.77	1,484.47	21.54	2,968.94
			0.15	100.00	14.00	12.10	1,855.59	24.21	3,711.17
	Rigid (>14-17t)	0.75	0.27	50.00	8.50	10.77	1,711.67	21.54	3,423.34
			0.15	100.00	17.00	12.10	2,139.59	24.21	4,279.17
	Rigid (>17-25t)	0.78	0.23	50.00	12.50	9.22	1,784.34	18.45	3,568.69
			0.14	100.00	25.00	10.87	2,230.43	21.73	4,460.86
	Rigid (>25t)	1.13	0.23	50.00	15.00	9.22	2,580.57	18.45	5,161.14
			0.14	100.00	30.00	5.43	3,225.71	10.87	6,451.43
	All rigids	0.82	0.29	50.00	17.50	11.59	1,884.53	23.19	3,769.06
	Artic (>3,5-33t)	0.81	0.14	50.00	17.00	5.71	1,863.67	11.42	3,727.34
			0.09	100.00	32.00	6.84	2,329.59	13.68	4,659.17
	Artic (>33t)	0.94	0.10	50.00	22.50	4.00	2,150.48	8.00	4,300.95
			0.06	100.00	45.00	4.99	2,688.09	9.97	5,376.19
	All artics	0.93	0.10	50.00	25.00	4.18	2,123.19	8.35	4,246.39
Vans	Class I	0.23	0.61	100.00	1.50	48.97	653.11	97.94	1,306.22
	Class II	0.32	0.63	100.00	2.50	50.67	917.05	101.35	1,834.09
	Class III	0.32	0.50	100.00	3.50	40.22	917.05	80.44	1,834.09
	Average	0.30	0.53	100.00	3.50	42.40	859.73	84.80	1,719.46

C

APPENDIX C: RESULTS OF CASE STUDIES.

I.   BRE Ravenscraig retrofit building results

Table C-1: Results for Ravenscraig-scenario 0

RAVENSCRAIG_0 - TonCO$_2$e	A1-A3	A4	A5	B4-B5	B6	C1-C4	Subtotal	%
Foundations	17,29	4,82	1,87	0,00	0,00	12,22	36,31	1,08%
Ground floor	35,12	0,19	1,41	31,86	0,00	0,47	69,27	2,05%
Upper floor	35,99	0,33	1,52	33,20	0,00	0,84	72,11	2,14%
Roof	19,14	0,25	0,62	11,90	0,00	0,64	32,67	0,97%
External wall 1	24,57	1,96	1,50	2,57	0,00	4,98	35,74	1,06%
Partition wall 1	5,30	0,43	0,33	0,89	0,00	1,08	8,06	0,24%
Internal walls	20,98	1,73	1,40	6,43	0,00	4,38	35,04	1,04%
Windows	0,38	0,08	0,00	0,08	0,00	0,21	0,75	0,02%
External doors	0,03	0,00	0,00	0,02	0,00	0,01	0,06	0,00%
Internal doors	0,15	0,02	0,00	0,08	0,00	0,04	0,28	0,01%
Construction	0,00	0,00	7,24	0,00	0,00	0,00	7,24	0,21%
Demolition	0,00	0,00	2,90	0,00	0,00	0,00	2,90	0,09%
Operational phase	0,00	0,00	0,00	0,00	3074,75	0,00	3074,75	91,13%
TOTAL Ton CO2e	**158,94**	**9,80**	**18,79**	**87,02**	**3.074,75**	**24,87**	**3.374,19**	**100,00%**

Table C-2: Results for Ravenscraig-scenario 1

RAVENSCRAIG_1 - TonCO$_2$e	A1-A3	A4	A5	B4-B5	B6	C1-C4	Subtotal	%
Foundations	17,29	4,82	1,87	0,00	0,00	12,22	36,30	1,72%
Ground floor	38,16	0,22	1,73	34,97	0,00	0,56	75,87	3,59%
Upper floor	35,99	0,33	1,52	33,20	0,00	0,84	72,10	3,41%
Roof	20,13	0,26	0,70	12,88	0,00	0,66	34,75	1,64%
External wall 1	25,85	1,97	1,60	3,83	0,00	5,01	38,41	1,82%
Partition wall 1	5,30	0,43	0,33	0,89	0,00	1,08	8,06	0,38%
Internal walls	20,98	1,73	1,40	6,43	0,00	4,38	35,03	1,66%
Windows	2,35	0,05	0,00	0,05	0,00	0,12	2,58	0,12%
External doors	0,03	0,00	0,00	0,02	0,00	0,01	0,06	0,00%
Internal doors	0,15	0,02	0,00	0,08	0,00	0,04	0,28	0,01%
Construction	0,00	0,00	10,06	0,00	0,00	0,00	10,06	0,48%
Demolition	0,00	0,00	4,03	0,00	0,00	0,00	4,03	0,19%
Operational phase	0,00	0,00	0,00	0,00	1797,38	0,00	1797,38	85,03%
TOTAL Ton CO2e	**166,22**	**9,82**	**23,23**	**92,34**	**1.797,38**	**24,92**	**2.113,91**	**100,00%**

Table C-3: Results for Ravenscraig-scenario 2

RAVENSCRAIG_2 - TonCO$_2$e	A1-A3	A4	A5	B4-B5	B6	C1-C4	Subtotal	%
Foundations	31,16	3,45	2,67	0,00	0,00	8,77	46,05	2,18%
Ground floor	38,47	0,22	1,76	35,27	0,00	0,56	76,29	3,61%
Upper floor	35,99	0,33	1,52	33,20	0,00	0,84	71,88	3,41%
Roof	14,81	0,29	0,60	7,31	0,00	0,75	23,75	1,13%
External wall 1	29,92	2,07	2,01	6,59	0,00	5,25	45,85	2,17%
Partition wall 1	3,05	0,42	0,22	0,89	0,00	1,06	5,63	0,27%
Internal walls	13,45	1,76	1,03	6,43	0,00	4,46	27,12	1,28%
Windows	2,35	0,05	0,00	0,05	0,00	0,12	2,57	0,12%
External doors	0,03	0,00	0,00	0,02	0,00	0,01	0,06	0,00%
Internal doors	0,15	0,02	0,00	0,08	0,00	0,04	0,28	0,01%
Construction	0,00	0,00	10,14	0,00	0,00	0,00	10,14	0,48%
Demolition	0,00	0,00	4,06	0,00	0,00	0,00	4,06	0,19%
Operational phase	0,00	0,00	0,00	0,00	1797,38	0,00	1797,38	85,14%
TOTAL Ton CO2e	**169,36**	**8,61**	**24,01**	**89,83**	**1.797,38**	**21,86**	**2.111,06**	**100,00%**

Table C-4: Results for Ravenscraig-scenario 3

RAVENSCRAIG_3 - TonCO$_2$e	A1-A3	A4	A5	B4-B5	B6	C1-C4	Subtotal	%
Foundations	31,16	3,45	2,67	0,00	0,00	8,77	46,05	2,19%
Ground floor	38,47	0,22	1,76	35,27	0,00	0,56	76,29	3,62%
Upper floor	35,99	0,33	1,52	33,20	0,00	0,84	71,88	3,41%
Roof	14,81	0,29	0,60	7,31	0,00	0,75	23,75	1,13%
External wall 1	24,75	2,09	1,76	6,59	0,00	5,31	40,51	1,92%
Partition wall 1	3,05	0,42	0,22	0,89	0,00	1,06	5,63	0,27%
Internal walls	13,45	1,76	1,03	6,43	0,00	4,46	27,12	1,29%
Windows	3,95	0,05	0,00	0,05	0,00	0,14	4,20	0,20%
External doors	0,03	0,00	0,00	0,02	0,00	0,01	0,06	0,00%
Internal doors	0,15	0,02	0,00	0,08	0,00	0,04	0,28	0,01%
Construction	0,00	0,00	10,07	0,00	0,00	0,00	10,07	0,48%
Demolition	0,00	0,00	4,03	0,00	0,00	0,00	4,03	0,19%
Operational phase	0,00	0,00	0,00	0,00	1797,38	0,00	1797,38	85,29%
TOTAL TonCO2e	**165,80**	**8,65**	**23,65**	**89,84**	**1.797,38**	**21,94**	**2.107,25**	**100,00%**

II.   CCG Yoker results

Table C-5: Results for Yoker case study

ACTUAL - YOKER_TonCO2e	A1-A3	A4	A5	B4-B5	B6	C1-C4	Subtotal	%
Foundations	685,09	86,17	70,24	8,91	0,00	369,62	1220,02	6,36%
Ground floor	157,77	5,60	9,70	110,05	0,00	24,01	307,13	1,60%
Upper floor	934,99	16,62	42,91	772,76	0,00	71,29	1838,57	9,58%
Roof	56,16	2,07	3,61	32,39	0,00	8,88	103,11	0,54%
External wall 1	254,56	4,81	12,26	179,24	0,00	20,62	471,49	2,46%
External wall 2	93,98	3,63	2,18	23,81	0,00	15,57	139,17	0,72%
Partition wall 1	53,76	3,11	2,67	31,15	0,00	13,35	104,04	0,54%
Partition wall 2	167,04	9,67	8,31	96,79	0,00	41,47	323,27	1,68%
Internal walls	26,56	1,54	1,32	15,39	0,00	6,59	51,40	0,27%
Windows	57,36	1,17	0,00	1,17	0,00	5,00	64,70	0,34%
External doors	0,10	0,01	0,00	0,00	0,00	0,05	0,17	0,00%
Internal doors	0,50	0,08	0,00	0,36	0,00	0,33	1,27	0,01%
Construction	0,00	0,00	81,71	0,00	0,00	0,00	81,71	0,43%
Demolition	0,00	0,00	0,00	0,00	0,00	32,71	32,71	0,17%
Operational phase	0,00	0,00	0,00	0,00	14458,55	0,00	14458,55	75,32%
TOTAL Ton CO2e	**2.487,87**	**134,47**	**234,92**	**1.272,02**	**14.458,55**	**609,49**	**19.197,31**	**100,00%**

D

APPENDIX D: MATLAB CALCULATION TOOL TRANSCRIPT

(1) General data gathering

(1.0) GENERAL INFORMATION DATA INPUT

```
disp '1. GENERAL INFORMATION SECTION:';
disp 'In this section the user will be inputing general information
about such as:';
disp 'name, location, building type, reference study period...etc';
disp ' ';
disp ' ';
```

(1.1) INPUTS FOR THE PROJECT GENERAL DATA

B_ means Building related topics P_ means project related topics. H_ means related to the high of the building or floors.

```
disp '1.1. INFORMATION ABOUT THE PROJECT';
disp ' ';
P_NAME=input('Name of the project? ','s');
disp ' ';
B_LOC=input('Location of the Project? ','s');
disp ' ';
disp '(1) 4-in-block ';
disp '(2) Terrace ';
disp '(3) Semi-detached ';
disp '(4) Detached (Default Option) ';
disp '(5) Multi-storey';
B_T=input('Please define the type of building for this assessment: ');
if B_T == 5
    B_T_NAME = 'MULTI';
    disp 'Type of Building selected is "Multi-storey".';
    disp ' ';
    T_EW=input('How many types of External wall there are? ');
    disp ' ';
    if exist ('T_EW','var') == 0
    T_EW = 1;
    end
else
    T_EW = 1;
    if B_T == 1
        B_T_NAME = '4-IN-BLOCK';
        disp 'Type of Building selected is "4-in-Block".';
    elseif B_T == 2
        B_T_NAME = 'TERRACE';
        disp 'Type of Building selected is "Terrace".';
    elseif B_T == 3
        B_T_NAME = 'SEMI-DETACHED';
        disp 'Type of Building selected is "Semi-Detached".';
    elseif B_T == 4
        B_T_NAME = 'DETACHED';
```

```
      disp 'Type of Building selected is "Detached".';
      else
          B_T_NAME = 'DETACHED';
          B_T = 4;
          disp 'By default the type of Building selected is "Detached".';
      end
 end
 disp ' ';
 disp ' ';
 disp '(1) Pitched - trusses >15°';
 disp '(2) Flat (default option)';
 B_TR=input('Please select the type of roof: ');
 disp ' ';
 if B_TR == 1
     disp 'Type of Roof selected is "Pitched Roof >15°".';
     ROOF_NAME = 'Pitched roof >15°';
     disp ' ';
     B_TR_T=input('Please define the inclination of the Roof in degrees?:
');

 else
     if B_TR == 2
     disp 'Type of Roof selected is "Flat Roof"';
     else
     disp 'By default "Flat Roof" is selected';
     B_TR_T = 2;
     end
     ROOF_NAME = 'Flat roof';
 end
 disp ' ';
 B_H=input('Please input the Height of the Building if known in metres?
');
 disp ' ';
 HL=input('Please input the Floor-Floor height of the Building if known
in metres?: ');
 disp ' ';
```

DEFINE TYPE OF STRUCTURE FRAME:

```
 disp 'PLEASE BE AWARE OF:';
 disp 'By default it is assumed that all Domestic Buildings have Load
Bearing walls structure frame.';
 B_TSF = 2;
 B_TSF_NAME = 'LOAD BEARING WALLS';
 B_TSM = 4;
 disp ' ';
 disp ' ';
```

(1.2) RSP INFORMATION DATA INPUT

```
disp '1.2. INFORMATION ABOUT THE LCA: ';
disp ' ';
RSP=input('Please input the Reference Study Period (RSP) of the
assessment in years?: ');
disp ' ';
disp ' ';
```

(1.3) BUILDING RELATED DATA & MEASURES FROM THE PROJECT

```
% FIRST CHECHK IF THERE IS A FILE WITH PROJECT MEASURES FROM M.EXCEL
% THE FILE NAME SHOULD BE THE FILE OF THE OPENED MATLAB PROJECT
disp '1.3. BUILDING MEASUREMENTS: ';
disp ' ';
P_FILE=strcat(P_NAME,'.xlsx');

if exist(P_FILE,'file') == 0
    disp 'Main Project Measures file was NOT FOUND' ;
    disp 'Please INPUT the following Project Measurements : ';
    disp ' ';
    B_FP_A=input('FOOTPRINT AREA (m2)? ') ;
    disp ' ';
    B_GIFA=input('GROSS INTERNAL FLOOR AREA (G.I.F.A.)(m2)? ');
    disp ' ';
    % difference between multi-storey and the rest
    if B_T == 5
        if T_EW == 2
            B_EW_A=input('EXTERNAL WALL - 1 AREA (m2)? ');
            disp ' ';
            B_EW2_A=input('EXTERNAL WALL - 2 AREA (m2)? ');
            disp ' ';
        elseif T_EW == 3
            B_EW_A=input('EXTERNAL WALL - 1 AREA (m2)? ');
            disp ' ';
            B_EW2_A=input('EXTERNAL WALL - 2 AREA (m2)? ');
            disp ' ';
            B_EW3_A=input('EXTERNAL WALL - 3 AREA (m2)? ');
            disp ' ';
        else
            B_EW_A=input('EXTERNAL WALL - 1 AREA (m2)? ');
            disp ' ';
        end

        B_PW1_A=input('PARTY WALL - 1 (FLAT-CLOSE) AREA (m2)? ');
        disp ' ';
        B_PW2_A=input('PARTY WALL - 1 (FLAT-FLAT) AREA (m2)? ');
        disp ' ';
    else
        B_EW_A=input('EXTERNAL WALL AREA (m2)? ');
```

273

```matlab
        disp ' ';
        B_PW1_A=input('PARTITION WALL AREA (m2)? ');
        disp ' ';
    end

    B_IW_A=input('INTERNAL WALL AREA (m2)? ');
    disp ' ';
    B_WIN_A=input('GLAZED WINDOW AREA (m2)? ');
    disp ' ';
    B_ROOF_A=input('NET ROOF AREA (m2)? ');
    disp ' ';
    B_EDO_A=input('EXTERNAL DOOR AREA (m2)? ');
    disp ' ';
    B_IDO_A=input('INTERNAL DOOR AREA (m2)? ');
    disp ' ';
    B_L_N=input('Number of Floors(No)? ');
    disp ' ';

% BETTER DECIDE THE ORIENTATION WITH A PICTURE WITH THE NUMBERS
% disp ' ';
% B_OR=input('MAIN ORIENTATION DIRECTION? (N(1),S(2),E(3),W(4),N-E(5),N-
W(6),S-E(7),S-W(8)): ');
% disp ' ';

else
    disp 'Main Project Measurements file was FOUND' ;
    disp ' ';
    [filenum,~,fileread] = xlsread(P_NAME,1);

    B_GIFA = filenum(5,1);
    B_FP_A = filenum(6,1);
    B_ROOF_A = filenum(7,1);
    B_EW_A = filenum(10,1);

    B_WIN_N = filenum(16,1);
    B_WIN_A = filenum(17,1);
    B_EDO_A = filenum(19,1);
    B_IDO_A = filenum(25,1);
    B_L_N = filenum(26,1)-1;

    if B_T == 1 || B_T == 3
        disp 'Please INPUT the following Project Measurements : ';
        disp ' ';
        B_PW1_A = input('Please input the Party Wall Area in m2? ');
        disp ' ';

    B_IW_A = filenum(13,1) - B_PW1_A;

    elseif B_T == 5
        disp 'Please INPUT the following Project Measurements : ';
```

274

```
        disp ' ';
        B_PW1_A = input('Please input the Party Wall (flat-close) Area
in m2? ');
        disp ' ';
        B_PW2_A = input('Please input the Party Wall (flat-flat) Area in
m2? ');
        disp ' ';
        B_IW_A = filenum(13,1) - B_PW1_A - B_PW2_A;

        if T_EW ~= 1
            B_EW2_A = filenum(11,1);

            if T_EW == 3
                B_EW3_A = filenum(12,1);
            end
        end
    else
        B_PW1_A = 0;
        B_IW_A = filenum(13,1);
    end
 end
 disp ' ';
 disp ' ';
```

(1.4) GENERATING THE EXCEL SHEET WITH GENERAL DATA OF THE PROJECT

```
 formatOut = 'yyyy_mm_dd';
 DATE=datestr(date,formatOut);
 ProjectGENdata = strcat('1_ProjectGEN_',P_NAME,'_', DATE,'.xlsx');
```
Define Headers and Values:

```
 genheader = {'Project General Data','','';
             'Project','Title',P_NAME;
             'Location','City',B_LOC;
             'Building','Type',B_T_NAME;
             'Structure','Type',B_TSF_NAME;
             'Levels', 'No', B_L_N;
             'LCA RSP',RSP,'Years';
             '','',''};

 genunits = {'Building Measurements','','';
             'Name','Unit','Value'};
 if B_T == 5
     if T_EW == 2
 genvalues1 = {'Footprint Area','m2',B_FP_A ;
     'G.I.F.A.','m2',B_GIFA ;
     'External Wall - 1 Area', 'm2', B_EW_A;
     'External Wall - 2 Area', 'm2', B_EW2_A;
     'Party Wall - 1 Area', 'm2', B_PW1_A;
```

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    'Party Wall - 2 Area', 'm2', B_PW2_A;
    'Internal Wall Area', 'm2', B_IW_A;
    'Net Roof Area', 'm2', B_ROOF_A;
    'Glazed Window Area', 'm2', B_WIN_A;
    'External Door Area', 'm2', B_EDO_A;
    'Internal Door Area', 'm2', B_IDO_A};

    % FOR WINDOWS:
    % xlswrite(ProjectGENdata, [genheader; genunits; genvalues1]);

    % FOR MAC:
    writecell([genheader; genunits; genvalues1],ProjectGENdata);

    elseif T_EW == 3
        genvalues1 = {'Footprint Area','m2',B_FP_A ;
        'G.I.F.A.','m2',B_GIFA ;
        'External Wall - 1 Area', 'm2', B_EW_A;
        'External Wall - 2 Area', 'm2', B_EW2_A;
        'External Wall - 3 Area', 'm2', B_EW3_A;
        'Party Wall - 1 Area', 'm2', B_PW1_A;
        'Party Wall - 2 Area', 'm2', B_PW2_A;
        'Internal Wall Area', 'm2', B_IW_A;
        'Net Roof Area', 'm2', B_ROOF_A;
        'Glazed Window Area', 'm2', B_WIN_A;
        'External Door Area', 'm2', B_EDO_A;
        'Internal Door Area', 'm2', B_IDO_A};

    % FOR WINDOWS:
    % xlswrite(ProjectGENdata, [genheader; genunits; genvalues1]);

    % FOR MAC:
    writecell([genheader; genunits; genvalues1],ProjectGENdata);

    end

elseif B_T == 1 || B_T == 3

genvalues2 = {'Footprint Area','m2',B_FP_A ;
    'G.I.F.A.','m2',B_GIFA ;
    'External Wall Area', 'm2', B_EW_A;
    'Partition Wall Area', 'm2', B_PW1_A;
    'Internal Wall Area', 'm2', B_IW_A;
    'Net Roof Area', 'm2', B_ROOF_A;
    'Glazed Window Area', 'm2', B_WIN_A;
    'External Door Area', 'm2', B_EDO_A;
    'Internal Door Area', 'm2', B_IDO_A};

% FOR MAC:
writecell([genheader; genunits; genvalues2],ProjectGENdata);
```

```
 else

 genvalues2 = {'Footprint Area','m2',B_FP_A ;
     'G.I.F.A.','m2',B_GIFA ;
     'External Wall Area', 'm2', B_EW_A;
     'Internal Wall Area', 'm2', B_IW_A;
     'Net Roof Area', 'm2', B_ROOF_A;
     'Glazed Window Area', 'm2', B_WIN_A;
     'External Door Area', 'm2', B_EDO_A;
     'Internal Door Area', 'm2', B_IDO_A};

 % FOR WINDOWS:
 % xlswrite(ProjectGENdata, [genheader; genunits; genvalues2]);

 % FOR MAC:
 writecell([genheader; genunits; genvalues2],ProjectGENdata);

 end
```

Reading the excel file generated and including all variables into the workspace:

```
 [gennum,gentxt,genread] = xlsread(ProjectGENdata);
```

(1.5) To execute the project raw data program automatically in order to continue:

```
 clc;

 formatOut = 'yyyy_mm_dd';
 DATE=datestr(date,formatOut);
 FILE_GEN_NAME = strcat(P_NAME,'_GEN_',DATE,'.mat');
 save (FILE_GEN_NAME);

 disp 'MOVE TO NEXT SECTION? ';
 CONTINUE_RAW=input('Do you want to conitnue with the "Raw Data base"
evaluation?(Y/N): ','s');
 disp ' ';
 if CONTINUE_RAW(1,1) == 'Y'
     run ABProjectRawDataBase2004Mac;
 else
     disp ' ';
     disp ' ';
     disp 'Thank you for using ©CRC General Program.';
     disp 'The information has been saved in "1_ProjectGENdata.xlsx"';
     disp ' ';
     disp ' ';
 end
```

The first main program file finishes here. There are no other program files executed automatically within it.

(2) Loading the database

```
% ©2023 CARLOS RODRIGUEZ CAMPOS/database for mac
% CREATING OWN SPECIFIC DATA BASE FROM THE SELECTION OF STRUCTURE IN
% GENERAL DATA INPUT
```

(2.0) Creating the Headers and units for excel file:

```
formatOut = 'yyyy_mm_dd';
DATE=datestr(date,formatOut);

ProjectRAWdb = strcat('2_ProjectRAW_',P_NAME,'_',DATE,'.xlsx');

rawdbheaders = {'CODE', 'NAME','Def.
WIDTH','DENSITY','RqSL','','','','MANUFACTURING',''};
rawdbunits = {'', '', '', '','','WASTE %','','','A1-A3','Unit'};
rawdbnames = {'', '', '(m)',
'(Kg/m3)','(Years)','SITE','DEMOLITION','REFURB.','AGGREGATED','Indicator
'};
```

(2.1) Load the database[1]:

```
run LCA_database
```

(2.3) Writing in excel all Data Base by Material Category

For MAC:

```
writecell([rawdbheaders; rawdbunits; rawdbnames;
DB_cement],ProjectRAWdb,'sheet','CEMENT&MORTAR');
writecell([rawdbheaders; rawdbunits; rawdbnames;
DB_clay],ProjectRAWdb,'sheet','CLAY');
writecell([rawdbheaders; rawdbunits; rawdbnames;
DB_concrete],ProjectRAWdb,'sheet','CONCRETE');
writecell([rawdbheaders; rawdbunits; rawdbnames;
DB_door],ProjectRAWdb,'sheet','DOORS');
writecell([rawdbheaders; rawdbunits; rawdbnames;
DB_finish],ProjectRAWdb,'sheet','FINISHES');
writecell([rawdbheaders; rawdbunits; rawdbnames;
DB_insulation],ProjectRAWdb,'sheet','INSULATION');
writecell([rawdbheaders; rawdbunits; rawdbnames;
DB_other],ProjectRAWdb,'sheet','OTHER');
writecell([rawdbheaders; rawdbunits; rawdbnames;
DB_plaster],ProjectRAWdb,'sheet','PLASTER');
% writecell([rawdbheaders; rawdbunits; rawdbnames;
DB_stone],ProjectRAWdb,'sheet','STONE');
writecell([rawdbheaders; rawdbunits; rawdbnames;
DB_timber],ProjectRAWdb,'sheet','TIMBER');
```

---

[1] The LCA database is defined on a separate program file, shown below.

```
writecell([rawdbheaders; rawdbunits; rawdbnames;
DB_window],ProjectRAWdb,'sheet','WINDOWS');
```

(2.4) RUN THE PROJECT SPECIFIC DATA BASE PROGRAM IN ORDER TO
CONTINUE:

```
clc;

formatOut = 'yyyy_mm_dd';
DATE=datestr(date,formatOut);
FILE_RAW_NAME = strcat(P_NAME,'_RAW_',DATE,'.mat');
save (FILE_RAW_NAME);

disp ' CONGRATULATIONS!!';
disp '©2023 CRC Database has been loaded correctly';
disp ' ';
disp 'MOVE TO NEXT SECTION? ';
CONTINUE_SPEC=input('Do you want to continue with the Building Elements
Definition?(Y/N): ','s');

if CONTINUE_SPEC(1,1) == 'Y'
    run ACProjectSpec_UK_Mac;
else
    disp ' ';
    disp ' ';
    disp ' ';
    disp 'Thank you for using ©CRC Raw DB Program.';
    disp 'Your database of materials is been saved in "2-
ProjectRAWdb.xlsx"';
    disp ' ';
    disp ' ';
end
```

The second main program file finishes here. All program files that are executed
automatically within it are highlighted on yellow and they will be shown below. In this
case it only applies to the "LCA database" program file.

(2.1.p) LCA database program file

Loading the Environmental database: Current value is the Aggregate A1-A3

INPUT THE MATERIAL DATABASE. ALL MATERIALS AND THEN MAKING THE GROUPS BY CATEGORY

Concrete has factors MJ/Kg modified acording the ICE Database for rebar=100Kg/m3. FOR IN-SITU CONCRETE: EMBODIED ENERGY:Basic fator=0.74. Rebar factor=1.04. Mod factor=1.78 EMBODIED CARBON:Basic fator=0.107. Rebar factor=0.077. Mod factor=0.184

```
% FOR PRE-CAST CONCRETE:
% EMBODIED ENERGY:Basic fator=0.74. Rebar factor=1.28. Mod factor=2.02
% EMBODIED CARBON:Basic fator=0.107. Rebar factor=0.0616. Mod
factor=0.1686

% FOR CONCRETE BLOCK:
% EMBODIED ENERGY:Basic fator=0.59. Rebar factor=1.28. Mod factor=2.02
% EMBODIED CARBON:Basic fator=0.107. Rebar factor=0.0616. Mod
factor=0.1686
BLANK={'','',0,0,100,0,0,0,0,'';
       '','',0,0,0,0,0,0,0,''};
CATEGORIES={'ALIAS','NAME','Thickness','Density','RSL','% SITE WASTE','%
of S_W sent to Lanfilling','% of S_W sent to
Incineration','GWP','KgCO2e/m2';
       '-','-',0,0,0,'% DEM WASTE','% of D_W sent to Lanfilling','% of
D_W sent to Incineration','EDEP','MJ'};
```

CEMENT AND MORTAR CATEGORY:

```
CEM_1={'CEM-1', 'Cement CEM I (Portland 94% Clinker)',0.01,1650,60,
90,90,90, 15.675, 'KgCO2e/m2';
     '','',0.01,0,0,5,100,100, 90.75, 'MJ/m2'};
CEM_2={'CEM-2', 'General Cement',0.015,1650,60, 90,90,90,
18.315,'KgCO2e/m2';
     '','',0.01,0,0,5,100,100, 111.62, 'MJ/m2'};
MOR_1={'MOR-1', 'Cement Dry Mortar (1:5)',0.015,1900,60, 90,90,90, 4.446,
'KgCO2e/m2';
     '','',0.01,0,0,5,100,100, 27.645, 'MJ/m2'};
MOR_2={'MOR-2', 'Cement Mortar (1:1:6)',0.013,1800,60, 90,90,90, 4.9842,
'KgCO2e/m2';
     '','',0.01,0,0,5,100,100, 25.74, 'MJ/m2'};
MOR_3={'MOR-3', 'General Cement Plaster',0.01,1400,60, 90,90,90, 1.82,
'KgCO2e/m2';
     '','',0.01,0,0,5,100,100, 25.2, 'MJ/m2'};
MOR_4={'MOR-4', 'Cement Mortar in single brick walls',0.1025,1900,30,
90,90,90, 4.9065, 'KgCO2e/m2';
     '','',0,0,0,5,100,100, 30.509, 'MJ/m2'};
MOR_5={'MOR-5', 'Cement Mortar in double brick walls',0.215,1900,30,
90,90,90, 10.292, 'KgCO2e/m2';
     '','',0,0,0,5,100,100, 63.994, 'MJ/m2'};
```

```
MOR_6={'MOR-6', 'Dot and Dab',0.010,1900,30, 90,90,90, 0.4787,
'KgCO2e/m2';
    '','',0,0,0,5,100,100, 2.9764, 'MJ/m2'};
```

INSULATION CATEGORY

```
INS_1A={'INS-1A', 'Mineral Wool Insulation 100mm', 0.1,105,30, 90,90,90,
13.44, 'KgCO2e/m2';
    '','',0,0,0, 10,100,100, 174.3, 'MJ/m2'};
INS_1B={'INS-1B', 'Mineral Wool Insulation 150mm', 0.15,105,30, 90,90,90,
20.16, 'KgCO2e/m2';
    '','',0,0,0, 10,100,100, 261.45, 'MJ/m2'};
INS_1C={'INS-1C', 'Mineral Wool Insulation 200mm', 0.2,105,30, 90,90,90,
26.88, 'KgCO2e/m2';
    '','',0,0,0, 10,100,100, 348.6, 'MJ/m2'};
INS_1D={'INS-1D', 'Mineral Wool Insulation 50mm', 0.05,105,30, 90,90,90,
6.72, 'KgCO2e/m2';
    '','',0,0,0, 10,100,100, 87.15, 'MJ/m2'};
INS_1E={'INS-1E', 'Mineral Wool Insulation 25mm', 0.05,105,30, 90,90,90,
3.36, 'KgCO2e/m2';
    '','',0,0,0, 10,100,100, 43.58, 'MJ/m2'};


INS_2A={'INS-2A', 'Woodwool board Insulation 100mm',0.1,173,30, 90,90,90,
16.95, 'KgCO2e/m2';
    '','',0,0,0, 8,100,100, 168.84, 'MJ/m2'};
INS_2B={'INS-2B', 'Woodwool board Insulation 150mm',0.15,173,30,
90,90,90, 25.43, 'KgCO2e/m2';
    '','',0,0,0, 8,100,100, 280.26, 'MJ/m2'};
INS_2C={'INS-2C', 'Woodwool board Insulation 200mm',0.2,173,30, 90,90,90,
33.9, 'KgCO2e/m2';
    '','',0,0,0, 8,100,100, 373.68, 'MJ/m2'};
INS_2D={'INS-2D', 'Woodwool board Insulation 50mm',0.05,173,30, 90,90,90,
33.9, 'KgCO2e/m2';
    '','',0,0,0, 8,100,100, 373.68, 'MJ/m2'};


INS_3A={'INS-3A', 'Rock Wool Insulation 100mm', 0.1,23,30, 90,90,90,
4.37, 'KgCO2e/m2';
    '','',0,0,0, 8,100,100, 65.52, 'MJ/m2'};
INS_3B={'INS-3B', 'Rock Wool Insulation 150mm', 0.15,23,30, 90,90,90,
6.55, 'KgCO2e/m2';
    '','',0,0,0, 8,100,100, 98.28, 'MJ/m2'};
INS_3C={'INS-3C', 'Rock Wool Insulation 200mm', 0.2,23,30, 90,90,90,
7.73, 'KgCO2e/m2';
    '','',0,0,0, 8,100,100, 131.04, 'MJ/m2'};
INS_3D={'INS-3D', 'Rock Wool Insulation 50mm', 0.05,23,30, 90,90,90,
2.18, 'KgCO2e/m2';
    '','',0,0,0, 8,100,100, 32.76, 'MJ/m2'};


INS_4A={'INS-4A', 'Fibreglass Glasswool Insulation 100mm', 0.1,10.5,30,
90,90,90, 1.41, 'KgCO2e/m2';
```

```
    '','',0,0,0, 8,100,100, 29.4, 'MJ/m2'};
INS_4B={'INS-4B', 'Fibreglass Glasswool Insulation 150mm', 0.15,10.5,30,
90,90,90, 2.12, 'KgCO2e/m2';
    '','',0,0,0, 8,100,100, 44.1, 'MJ/m2'};
INS_4C={'INS-4C', 'Fibreglass Glasswool Insulation 200mm', 0.2,10.5,30,
90,90,90, 2.83, 'KgCO2e/m2';
    '','',0,0,0, 8,100,100, 58.8, 'MJ/m2'};

INS_5A={'INS-5A', 'Expanded Polystyrene Insulation 100mm',0.1,105,30,
90,90,90, 14.80, 'KgCO2e/m2';
    '','',0,0,0, 10,100,100, 398.7, 'MJ/m2'};
INS_5B={'INS-5B', 'Expanded Polystyrene Insulation 150mm',0.15,105,30,
90,90,90, 22.21, 'KgCO2e/m2';
    '','',0,0,0, 10,100,100, 598.05, 'MJ/m2'};
INS_5C={'INS-5C', 'Expanded Polystyrene Insulation 200mm',0.2,105,30,
90,90,90, 29.61, 'KgCO2e/m2';
    '','',0,0,0, 10,100,100, 797.4, 'MJ/m2'};
INS_5D={'INS-5D', 'Expanded Polystyrene Insulation 50mm',0.05,105,30,
90,90,90, 7.40, 'KgCO2e/m2';
    '','',0,0,0, 10,100,100, 199.35, 'MJ/m2'};
INS_5E={'INS-5E', 'Expanded Polystyrene Insulation YOKER
foundations',0.15,105,30, 90,90,90, 14.69, 'KgCO2e/m2';
    '','',0,0,0, 10,100,100, 304.70, 'MJ/m2'};
INS_5F={'INS-5F', 'Expanded Polystyrene Insulation 170mm',0.17,105,30,
90,90,90, 25.16, 'KgCO2e/m2';
    '','',0,0,0, 10,100,100, 677.79, 'MJ/m2'};
INS_5G={'INS-5G', 'Expanded Polystyrene Insulation 80mm',0.08,105,30,
90,90,90, 11.84, 'KgCO2e/m2';
    '','',0,0,0, 10,100,100, 318.96, 'MJ/m2'};
```

CLAY CATEGORY

```
CLAY_1={'CLAY-1', 'UK Single Clay Brick Wall',0.1025,1900,60, 50,50,50,
38.03, 'KgCO2e/m2';
    '','',0.19,0,0, 5,100,100, 444.51, 'MJ/m2'};
CLAY_2={'CLAY-2', 'UK Double Clay Brick Wall',0.215,1900,60, 50,50,50,
79.02, 'KgCO2e/m2';
    '','',0.398,0,0, 5,100,100, 907.45, 'MJ/m2'};
CLAY_3={'CLAY-3', 'Clay Brick Slip',0.013,1700,60, 50,50,50, 4.4474,
'KgCO2e/m2';
    '','',0,0,0, 7.5,100,100, 55.593, 'MJ/m2'};
CLAY_4={'CLAY-4', 'General Clay Tile',0.012,1900,60, 50,50,50, 10.944,
'KgCO2e/m2';
    '','',0.025,0,0, 7.5,100,100, 148.2, 'MJ/m2'};
CLAY_5={'CLAY-5', 'Foundations UK Single Clay Brick Wall',0.1025,1900,60,
50,50,50, 13.86, 'KgCO2e/m2';
    '','',0,0,0, 5,100,100, 161.99, 'MJ/m2'};
CLAY_6={'CLAY-6', 'Foundations UK Double Clay Brick Wall',0.215,1900,60,
50,50,50, 19.24, 'KgCO2e/m2';
```

```
      '','',0,0,0, 5,100,100, 224.30, 'MJ/m2'};
```

for validation with C.Galan:

```
CLAY_7={'CLAY-7', 'Spanish Brick Wall (d=0,24m)',0.240,1705.84,60,
50,50,50, 59.237, 'KgCO2e/m2';
      '','',0.18,0,0, 5,100,100, 626.171, 'MJ/m2'};
CLAY_8={'CLAY-8', 'Spanish Brick Wall (d=0,365m)',0.365,1705.84,60,
50,50,50, 86.486, 'KgCO2e/m2';
      '','',0.35,0,0, 5,100,100, 914.209, 'MJ/m2'};
CLAY_9={'CLAY-9', 'Spanish Brick Wall (d=0,49m)',0.490,1705.84,60,
50,50,50, 102.618, 'KgCO2e/m2';
      '','',0.532,0,0, 5,100,100, 1152.539, 'MJ/m2'};
```

PLASTER CATEGORY

```
PLAST_1={'PLAST-1', 'General Gypsum/Cement Plaster',0.01,1120,15,
90,90,90, 1.45, 'KgCO2e/m2';
      '','',0,0,0, 5,100,100, 20.16, 'MJ/m2'};
PLAST_2={'PLAST-2', 'Lime Plaster (1:1:6)',0.01,1400,15, 90,90,90, 2.98,
'KgCO2e/m2';
      '','',0,0,0, 5,100,100, 15.4, 'MJ/m2'};
PLAST_3={'PLAST-3', 'Plasterboard',0.0125,900,30, 98,100,99, 4.38,
'KgCO2e/m2';
      '','',0.06,0,0, 8,100,100, 75.938, 'MJ/m2'};
PLAST_4={'PLAST-4', 'Light Metal Studs C shape 70x50mm @600',0.05,900,30,
98,100,99, 0.63, 'KgCO2e/m2';
      '','',0,0,0, 8,100,100, 7.46, 'MJ/m2'};
PLAST_5={'PLAST-5', 'Light Metal Studs C shape 50x50mm @600',0.05,900,30,
98,100,99, 0.54, 'KgCO2e/m2';
      '','',0,0,0, 8,100,100, 6.36, 'MJ/m2'};
PLAST_6={'PLAST-6', 'Double Plasterboard',0.025,900,30, 98,100,99, 8.76,
'KgCO2e/m2';
      '','',0.12,0,0, 8,100,100, 151.87, 'MJ/m2'};
```

CONCRETE CATEGORY

```
CON_1={'CON-1', 'In-situ Concrete 20/25 Raft Foundation
(d=50/30cm)',0.5,2300,60, 50,50,50, 96.07, 'KgCO2e/m2';
      '','',0,0,0, 7.5,100,100, 951.55, 'MJ/m2'};
CON_2={'CON-2', 'In-situ Concrete 20/25 Strip Foundation
(60cmx40cm)',0.4,2300,60, 50,50,50, 74.03, 'KgCO2e/m2';
      '','',0,0,0, 7.5,100,100, 716.15, 'MJ/m2'};
CON_3={'CON-3', 'Pre-cast concrete  20/25 (thck=20cm)',0.2,2300,60,
50,50,50, 77.556, 'KgCO2e/m2';
      '','',0,0,0, 2.5,100,100, 929.2, 'MJ/m2'};
CON_4={'CON-4', 'Dense Concrete block wall (d=10cm)',0.1,2000,60,
50,50,50, 20.27, 'KgCO2e/m2';
      '','',0,0,0, 5,100,100, 148.54, 'MJ/m2'};
CON_5={'CON-5', 'Dense Concrete block wall (d=20cm)',0.1,2000,60,
50,50,50, 40.54, 'KgCO2e/m2';
```

```
    '','',0,0,0, 5,100,100, 297.07, 'MJ/m2'};
CON_6={'CON-6', 'Dens concrete dintel (10x300x150mm)',0.06,1950,60,
50,50,50, 6.4672, 'KgCO2e/m2';
    '','',0,0,0, 5,100,100, 11.873, 'MJ/m2'};
CON_7_A={'CON-7_A', 'In-situ Concrete 20/25 RAVENSCRAIG Strips Foundation
(60x40cm)',0.175,2300,60, 50,50,50, 74.03, 'KgCO2e/m2';
    '','',0,0,0, 7.5,100,100, 716.15, 'MJ/m2'};
CON_7_B={'CON-7_B', 'In-situ Concrete 20/25 RAVENSCRAIG Raft Foundation
(60x50cm_30cm)',0.4,2300,60, 50,50,50, 169.51, 'KgCO2e/m2';
    '','',0,0,0, 7.5,100,100, 1639.82, 'MJ/m2'};
CON_8={'CON-8', 'In-situ Concrete 20/25 YOKER Strips Foundation
(60x60/100cm)',0.25,2300,60, 50,50,50, 121.86, 'KgCO2e/m2';
    '','',0,0,0, 7.5,100,100, 1360.80, 'MJ/m2'};
CON_9={'CON-9', 'In-situ Concrete 20/25 YOKER Slab
(d=175mm)',0.175,2300,60, 50,50,50, 74.06, 'KgCO2e/m2';
    '','',0,0,0, 7.5,100,100, 716.45, 'MJ/m2'};
CON_10={'CON-10', 'Concrete screed (d=50mm)',0.05,2300,60, 50,50,50,
10.50, 'KgCO2e/m2';
    '','',0,0,0, 7.5,100,100, 73.50, 'MJ/m2'};
CON_11={'CON-11', 'Concrete screed (d=70mm)',0.07,2300,60, 50,50,50,
14.70, 'KgCO2e/m2';
    '','',0,0,0, 7.5,100,100, 102.90, 'MJ/m2'};
CON_12={'CON-12', 'Concrete YOKER piles (diam=750mm)',2.6,2300,80,
50,50,50, 1103.02, 'KgCO2e/m2';
    '','',0,0,0, 7.5,100,100, 10670.52, 'MJ/m2'};


CON_13={'CON-13', 'Light Concrete block wall (d=20cm)',0.2,1090,60,
50,50,50, 30.86, 'KgCO2e/m2';
    '','',0,0,0, 5,100,100, 224.50, 'MJ/m2'};
CON_14={'CON-14', 'Light Concrete block wall (d=35cm)',0.35,1090,60,
50,50,50, 54.00, 'KgCO2e/m2';
    '','',0,0,0, 5,100,100, 392.88, 'MJ/m2'};
CON_15={'CON-15', 'In-situ concrete 20/25MPa wall
(thck=25cm)',0.25,2450,60, 50,50,50, 81.260, 'KgCO2e/m2';
    '','',0,0,0, 5,100,100, 688.015, 'MJ/m2'};
CON_16={'CON-16', 'Light Concrete block wall (d=30cm)',0.3,1090,60,
50,50,50, 46.28, 'KgCO2e/m2';
    '','',0,0,0, 5,100,100, 336.75, 'MJ/m2'};
CON_17={'CON-17', 'Light Concrete block wall (d=10cm)',0.1,1090,60,
50,50,50, 15.43, 'KgCO2e/m2';
    '','',0,0,0, 5,100,100, 112.25, 'MJ/m2'};
CON_18={'CON-18', 'Light Concrete block wall (d=40cm)',0.1,1090,60,
50,50,50, 61.71, 'KgCO2e/m2';
    '','',0,0,0, 5,100,100, 449.00, 'MJ/m2'};
```

OTHER CATEGORY

```
OTHER_1={'OTHER-1', 'Dump Membrane',0.003,1120,60, 30,0,0, 4.03,
'KgCO2e/m2';
    '','',0,0,0, 15,100,100, 450.24, 'MJ/m2'};
```

```
OTHER_2={'OTHER-2', 'General Soil',0.5,1450,60, 30,0,0, 17.52,
'KgCO2e/m2';
    '','',0,0,0, 15,100,100, 328.5, 'MJ/m2'};
OTHER_3={'OTHER-3', 'General Sand',0.005,0.028,60, 30,0,0, 0.57,
'KgCO2e/m2';
    '','',0,0,0, 15,100,100, 0.90, 'MJ/m2'};
OTHER_4={'OTHER-4', 'General Rubber, hardwood & Cement
Mixture',0.0125,1200,60, 90,90,90, 1365, 'KgCO2e/m2';
    '','',0,0,0, 5,100,100, 42.75, 'MJ/m2'};
OTHER_5={'OTHER-5', 'General Aggregate',0.500,2240,60, 30,0,0, 5.82,
'KgCO2e/m2';
    '','',0.25,0,0, 10,100,100, 92.96, 'MJ/m2'};
OTHER_6={'OTHER-6', 'Air Gap', 0.00, 0, 60, 0,0,0, 0, 'KgCO2e/m2';
    '','',0.18,0,0, 0,100,100, 0, 'MJ/m2'};
OTHER_7={'OTHER-7', 'Gravel for Strip Foundations',0.50,2240,60, 30,0,0,
3.53, 'KgCO2e/m2';
    '','',0,0,0, 10,100,100, 56.36, 'MJ/m2'};
OTHER_8={'OTHER-8', 'Gravel for YOKER Strip Foundations',0.25,2240,60,
30,0,0, 2.01, 'KgCO2e/m2';
    '','',0,0,0, 10,100,100, 32.11, 'MJ/m2'};
OTHER_9={'OTHER-9', 'Glue for vinyl finish',0.002,1200,60, 30,0,0, 7.15,
'KgCO2e/m2';
    '','',0,0,0, 10,100,100, 211.20, 'MJ/m2'};
```

for validation with C.Galan:

```
OTHER_10={'OTHER-10', 'Stabilised soil wall d=0,24m',0.24,1790,60,
50,50,50, 23.06, 'KgCO2e/m2';
    '','',0,0,0, 10,100,100, 327.64, 'MJ/m2'};
OTHER_11={'OTHER-11', 'Stabilised soil wall d=0,30m',0.30,1790,60,
50,50,50, 30.02, 'KgCO2e/m2';
    '','',0,0,0, 10,100,100, 409.55, 'MJ/m2'};
OTHER_12={'OTHER-12', 'Stabilised soil wall d=0,36m',0.36,1790,60,
50,50,50, 36.04, 'KgCO2e/m2';
    '','',0,0,0, 10,100,100, 511.67, 'MJ/m2'};
OTHER_13={'OTHER-13', 'Stabilised soil wall d=0,42m',0.42,1790,60,
50,50,50, 42.03, 'KgCO2e/m2';
    '','',0,0,0, 10,100,100, 596.95, 'MJ/m2'};
```

TIMBER CATEGORY

```
TIMBER_1={'TIMBER-1', 'Timber Particle Boards',0.022,800,30, 85,90,90,
19.18, 'KgCO2e/m2';
    '','',0.157,0,0, 0,100,100, 281.60,'MJ/m2'};
TIMBER_2={'TIMBER-2', 'Glue Laminated Timber (GLT)',0.4,460,60, 46,58,58,
6.62, 'KgCO2e/m2';
    '','',0,0,0, 0,100,100, 110.40,'MJ/m2'};
TIMBER_3={'TIMBER-3', 'Laminated Veneer Lumber (LVL)',0.1,540,60,
46,58,58, 1.75, 'KgCO2e/m2';
    '','',0.769,0,0, 0,100,100, 25.65,'MJ/m2'};
```

```
TIMBER_4={'TIMBER-4', 'Oriented Strand Board (OSB)',0.09,640,30,
85,90,90, 5.76, 'KgCO2e/m2';
    '','',0.692,0,0, 10,100,100, 86.40,'MJ/m2'};
TIMBER_5={'TIMBER-5', 'Timber Plywood',0.0125,540,60, 46,58,58, 7.42,
'KgCO2e/m2';
    '','',0.096,0,0, 10,100,100, 101.25,'MJ/m2'};
TIMBER_6={'TIMBER-6', 'Timber I-Joists @400mm',0.0125,540,60, 46,58,58,
6.01, 'KgCO2e/m2';
    '','',0,0,0, 0,100,0, 88.81,'MJ/m2'};
TIMBER_7={'TIMBER-7', 'Sawn Timber Roof Truss 30°',0.0125,540,60,
46,58,58, 42.53, 'KgCO2e/m2';
    '','',0,0,0, 0,100,0, 621.60,'MJ/m2'};
TIMBER_8={'TIMBER-8', 'Sawn Softwood for doors',0.0125,510,60, 46,58,58,
42.44, 'KgCO2e/m2';
    '','',0,0,0, 0,100,100, 621.60,'MJ/m2'};
TIMBER_9={'TIMBER-9', 'Cross Laminated Timber (CLT) walls',0.116,460,60,
46,58,58, 46.42, 'KgCO2e/m2';
    '','',0.892,0,0, 0,100,100, 640.32,'MJ/m2'};
TIMBER_10={'TIMBER-10', 'Cross Laminated Timber (CLT)
floors',0.119,460,60, 46,58,58, 47.62, 'KgCO2e/m2';
    '','',0.915,0,0, 0,100,100, 656.88,'MJ/m2'};
TIMBER_11={'TIMBER-11', 'Softwood battens 50x50mm',0.05,460,60, 46,58,58,
1.53, 'KgCO2e/m2';
    '','',0,0,0, 0,100,100, 21.25,'MJ/m2'};
TIMBER_12={'TIMBER-12', 'Softwood battens 70x50mm',0.07,460,60, 46,58,58,
2.142, 'KgCO2e/m2';
    '','',0,0,0, 0,100,100, 29.75,'MJ/m2'};
TIMBER_13={'TIMBER-13', 'Timber Studs 150x50mm',0.150,460,60, 46,58,58,
4.59, 'KgCO2e/m2';
    '','',0,0,0, 0,100,100, 63.75,'MJ/m2'};
TIMBER_14={'TIMBER-14', 'HPL panel 8mm',0.008,460,60, 46,58,58, 37.40,
'KgCO2e/m2';
    '','',0,0,0, 0,100,100, 804,'MJ/m2'};
TIMBER_15={'TIMBER-15', 'Timber I-Joists @600mm',0.0125,540,60, 46,58,58,
59.21, 'KgCO2e/m2';
    '','',0,0,0, 0,100,0, 4.01,'MJ/m2'};
```

FINISHES CATEGORY

```
FIN_1={'FINISH-1', 'General paint Single Coat',0.01,800,30, 95,95,95,
0.4369, 'KgCO2e/m2';
    '','',0,0,0, 10,100,100, 10.511,'MJ/m2'};
FIN_2={'FINISH-2', 'General paint Double Coat',0.01,800,30, 95,95,95,
0.8739, 'KgCO2e/m2';
    '','',0,0,0, 10,100,100, 21.021,'MJ/m2'};
FIN_3={'FINISH-3', 'Waterborne Paint',0.01,800,30, 95,95,95, 0.3814,
'KgCO2e/m2';
    '','',0,0,0, 10,100,100, 9.8,'MJ/m2'};
FIN_4={'FINISH-4', 'Solverntborne paint',0.01,800,30, 95,95,95, 0.5646,
'KgCO2e/m2';
```

```
    '','',0,0,0, 10,100,100, 9.8,'MJ/m2'};
FIN_5={'FINISH-5', 'General Carpet',0.022,800,30, 90,90,90, 187,
'KgCO2e/m2';
    '','',0.367,0,0, 5,100,100, 9.8,'MJ/m2'};
FIN_6={'FINISH-6', 'General Wallpaper',0.022,800,30, 85,90,90, 187,
'KgCO2e/m2';
    '','',0,0,0, 5,100,100, 27.5,'MJ/m2'};
FIN_7={'FINISH-7', 'General Vinyl Flooring',0.004,1200,30, 82,90,82, 187,
'KgCO2e/m2';
    '','',0.024,0,0, 5,100,100, 10,'MJ/m2'};
FIN_8={'FINISH-8', 'Slate Slips',0.012,1600,30, 90,90,90, 43.97,
'KgCO2e/m2';
    '','',0.02,0,0, 5,100,100, 1260.3,'MJ/m2'};
FIN_9={'FINISH-9', 'Slate Slips for Roof 30°',0.012,1600,30, 90,90,90,
55.40, 'KgCO2e/m2';
    '','',0.02,0,0, 5,100,100, 1587.98,'MJ/m2'};
FIN_10={'FINISH-10', 'Vinyl brick slips',0.004,1200,30, 82,90,82, 157.08,
'KgCO2e/m2';
    '','',0.02,0,0, 5,100,100, 8.40,'MJ/m2'};
```

WINDOWS CATEGORY

```
WIN_1={'WINDOW-1', 'Window Single Glazed-TIMBER',0.15,800,30, 0,100,0,
8.33, 'KgCO2e/m2';
    '','',0,0,0, 0,100,0, 159.72,'MJ/m2'};
WIN_2={'WINDOW-2', 'Window Double Glazed-ALUM',0.15,460,30, 0,100,0,
52.08, 'KgCO2e/m2';
    '','',0,0,0, 0,0,0, 1013.89,'MJ/m2'};
WIN_3={'WINDOW-3', 'Window Double Glazed-PVC',0.15,540,30, 0,100,0,
87.50, 'KgCO2e/m2';
    '','',0,0,0, 0,100,0, 1715.28,'MJ/m2'};
WIN_4={'WINDOW-4', 'Window Double Glazed-TIMBER',0.15,540,30, 0,100,0,
17.36, 'KgCO2e/m2';
    '','',0,0,0, 0,100,0, 340.28,'MJ/m2'};
```

DOORS CATEGORY:

```
INT_DOOR_1={'INT. DOOR-1', 'Timber Framed Interior Door',0.05,540,40,
46,58,58, 3.79, 'KgCO2e/m2';
    '','',0,0,0, 0,100,100, 47.57,'MJ/m2'};
INT_DOOR_2={'INT. DOOR-2', 'PVC Framed Interior Door',0.1,540,60,
0,100,0, 9.71, 'KgCO2e/m2';
    '','',0,0,0, 0,100,0, 117.03,'MJ/m2'};
EXT_DOOR_1={'EXT. DOOR-2', 'Timber Framed Exterior Door',0.05,540,40,
46,58,58, 3.79, 'KgCO2e/m2';
    '','',0,0,0, 0,100,100, 47.57,'MJ/m2'};
EXT_DOOR_2={'EXT. DOOR-1', 'PVC Framed Exterior Door',0.1,540,60,
0,100,0, 9.71, 'KgCO2e/m2';
    '','',0,0,0, 0,100,0, 117.03,'MJ/m2'};
```

MAKING THE GROUPS OF MATERIAL BY MATERIALS CATEGORY:

CEMENT & CONCRETE MATERIALS:

```
DB_cement = [CEM_1; CEM_2; MOR_1; MOR_2; MOR_3; MOR_4; MOR_5; MOR_6];
DB_concrete = [CON_1; CON_2; CON_3; CON_4; CON_5;
               CON_6; CON_7_A; CON_7_B; CON_8; CON_9; CON_10;
               CON_11; CON_12];
```

CLAY MATERIALS

```
DB_clay = [CLAY_1; CLAY_2; CLAY_3; CLAY_4; CLAY_5; CLAY_6; CLAY_7;
CLAY_8; CLAY_9;];
```

INSULATION MATERIALS

```
DB_insulation = [INS_1A;INS_1B;INS_1C;INS_1D;
                 INS_2A;INS_2B;INS_2C;
                 INS_3A;INS_3B;INS_3C;
                 INS_4A;INS_4B;INS_4C;
                 INS_5A;INS_5B;INS_5C;INS_5D;INS_5E;INS_5F;INS_5G];
```

FINISH MATERIALS

```
DB_finish = [FIN_1; FIN_2; FIN_3; FIN_4; FIN_5;
             FIN_6; FIN_7; FIN_8; FIN_9; FIN_10;];
```

PLASTER MATERIALS

```
DB_plaster = [PLAST_1; PLAST_2; PLAST_3; PLAST_4; PLAST_5; PLAST_6];
```

TIMBER MATERIALS

```
DB_timber = [TIMBER_1; TIMBER_2; TIMBER_3; TIMBER_4; TIMBER_5;
             TIMBER_6; TIMBER_7; TIMBER_8; TIMBER_9; TIMBER_10;
             TIMBER_11; TIMBER_12; TIMBER_13; TIMBER_14];
```

WINDOW MATERIALS

```
DB_window = [WIN_1; WIN_2; WIN_3; WIN_4];
```

INTERIAL DOOR MATERIALS

```
DB_door = [INT_DOOR_1; INT_DOOR_2; EXT_DOOR_1; EXT_DOOR_2];
```

Other materials:

```
DB_other = [OTHER_1; OTHER_2; OTHER_3; OTHER_4; OTHER_5;
            OTHER_6; OTHER_7; OTHER_8; OTHER_9;
            OTHER_10; OTHER_11; OTHER_12; OTHER_13];
```

PUTTING ALL MATERIALS TOGETHER:

```
DB_all = [cemvalues; convalues; clayvalues; insvalues; finishvalues; plastvalues;
timbvalues; winvalues; doorvalues; othervalues];
```

(3) Specific building elements definition

```
% Creating specific data base reading from raw contruction materials
% database created with 'projectrawdatabase' previously.
% PREPARING SCENARIO AND FILE NAME:
clc;
disp ' ';
disp 'If the scenario assessed has no name or number, the default option
(0) will be assigned ';
disp ' ';
SCENARIO=input('Please define a number or name for the scenario assessed:
','s');
EXIST_SCENARIO = exist ('SCENARIO','var');

if EXIST_SCENARIO == 0
    SCENARIO = 0;
    disp ' ';
    disp ' ';
    disp 'Default scenario (0) is been selected';
    disp ' ';
end
disp ' ';
disp ' ';
formatOut = 'yyyy_mm_dd';
DATE=datestr(date,formatOut);
FILE_SPEC_NAME = strcat(P_NAME,'_',SCENARIO,'_SPEC_',DATE,'.mat');
```

FILE NAME WHEN VALIDATING WITH CGALAN PAPER:

FILE_SPEC_NAME = strcat(P_NAME,'_SPEC_',DATE,'.mat');
(3.0) GENERATING EXCEL FILE FOR BASELINE SCENARIO:

```
ProjectSPECbase = strcat('3_ProjectSPEC_',P_NAME,'_',SCENARIO,'_',
DATE,'.xlsx');

specheaders = {'ELEMENT','CODE', 'NAME','Def.
WIDTH','DENSITY','RqSL','','','','MANUFACTURING','','','','','','','OPERA
TION','','','','','END-OF-LIFE','','','','','','','',''};
specunits = {'','', '', '', '','','WASTE %','','','A1-
A3','A4','A5_a','A5_b','A5_c','A5_d','A5_e','B4_a','B4_b','B4_c','B4_d','
B6','C1','C2','C3','C4','A','B4','C','','Unit'};
specnames = {'','', '', '(m)',
'(Kg/m3)','Years','SITE','DEMOLITION','REFURB.','MANUFACTURING','TRANSPOR
T','CONS-OSW','CONS-TRA_1','CONS-DISPOSAL','CONS-TRA_2','CONS','REPCT-
MAT','REPCT-TRA_1','REPCT-DISPOSAL','REPCT-
TRA_2','USE','DEM','TRA_2','WASTE-PRO','DISPOSAL','STAGE A','SUB-STAGE
B4','STAGE C','SUB-TOTAL','Indicator'};

% Subtotals line:
subtotal={'','','','','','','', 'Subtotal','','KgCO2e/m2';
```

```
            '','','','','','','', 'Subtotal','','MJ/m2'};
```

Writing all data to excel:

It has been used the headers from "RawDataBase" for simplicity

```
% For Windows:
% xlswrite(ProjectSPECbase,[specheaders; specunits;
specnames],'FOUNDATIONS');
% xlswrite(ProjectSPECbase,[specheaders; specunits;
specnames],'GROUND_FLOORS');
% xlswrite(ProjectSPECbase,[specheaders; specunits;
specnames],'UPPER_FLOORS');
% xlswrite(ProjectSPECbase,[specheaders; specunits;
specnames],'EXT_WALLS');
% xlswrite(ProjectSPECbase,[specheaders; specunits;
specnames],'INT_WALLS');
% xlswrite(ProjectSPECbase,[specheaders; specunits;
specnames],'PAR_WALLS');
% xlswrite(ProjectSPECbase,[specheaders; specunits; specnames],'ROOF');
% xlswrite(ProjectSPECbase,[specheaders; specunits;
specnames],'WINDOWS');
% xlswrite(ProjectSPECbase,[specheaders; specunits; specnames],'DOORS');


% For Mac:
writecell([specheaders; specunits;
specnames],ProjectSPECbase,'sheet','FOUNDATIONS');
writecell([specheaders; specunits;
specnames],ProjectSPECbase,'sheet','GROUND_FLOORS');
writecell([specheaders; specunits;
specnames],ProjectSPECbase,'sheet','UPPER_FLOORS');
writecell([specheaders; specunits;
specnames],ProjectSPECbase,'sheet','ROOF');
writecell([specheaders; specunits;
specnames],ProjectSPECbase,'sheet','EXT_WALLS-1');
if T_EW ~= 1
    writecell([specheaders; specunits;
specnames],ProjectSPECbase,'sheet','EXT_WALLS-2');
    if T_EW == 3
    writecell([specheaders; specunits;
specnames],ProjectSPECbase,'sheet','EXT_WALLS-3');
    end
end
writecell([specheaders; specunits;
specnames],ProjectSPECbase,'sheet','PAR_WALLS-1');
if B_T == 5
    writecell([specheaders; specunits;
specnames],ProjectSPECbase,'sheet','PAR_WALLS-2');
end
writecell([specheaders; specunits;
specnames],ProjectSPECbase,'sheet','INT_WALLS');
```

```
writecell([specheaders; specunits;
specnames],ProjectSPECbase,'sheet','WINDOWS');
writecell([specheaders; specunits;
specnames],ProjectSPECbase,'sheet','EXT_DOORS');
writecell([specheaders; specunits;
specnames],ProjectSPECbase,'sheet','INT_DOORS');
```

Writing the name of the element on excel

SUBSTRUCTURE:

Foundations

```
F_name_b = {'Foundations-B';'(F_B)'};
```

Floors: ground, upper and ceiling

```
GF_name_b = {'Ground Floor-B';'(GF_B)'};



UF_name_b = {'Upper Floor-B';'(UF_B)'};

% Roofs
R_name_b = {'Roof-B';'(ROOF_B)'};
```

Walls: external, internal and partitions

```
EW_name_b = {'External Wall-B';'(EW_B)'};

if T_EW ~= 1
    EW2_name_b = {'External Wall 2-B';'(EW2_B)'};
    if T_EW == 3
    EW3_name_b = {'External Wall 3-B';'(EW3_B)'};
    end
end
```

Internal Wall

```
IW_name_b = {'Internal Wall-B';'(IW_B)'};
```

Party walls

```
PW_name_b = {'Partition Wall-B';'(PW_B)'};

if B_T == 5
    PW2_name_b = {'Partition Wall 2-B';'(PW2_B)'};
end
```

Windows and external Doors

```
ED_name_b = {'External Doors-B';'(ED_B)'};


W_name_b = {'Windows-B';'(W_B)'};
```

Internal Doors

```
ID_name_b = {'Internal Doors-B';'(ID_B)'};
```

WRITING IN THE EXCEL ALL NAMES SHEETS

```
% For Windows:
% xlswrite(ProjectSPECbase,F_name_b,'FOUNDATIONS','A4');
% xlswrite(ProjectSPECbase,GF_name_b,'GROUND_FLOORS','A4');
% xlswrite(ProjectSPECbase,UF_name_b,'UPPER_FLOORS','A4');
% xlswrite(ProjectSPECbase,R_name_b,'ROOF','A4');
% xlswrite(ProjectSPECbase,EW_name_b,'EXT_WALLS-1','A4');
% xlswrite(ProjectSPECbase,PW_name_b,'PAR_WALLS-1','A4');
% xlswrite(ProjectSPECbase,IW_name_b,'INT_WALLS','A4');
% xlswrite(ProjectSPECbase,W_name_b,'WINDOWS','A4');
% xlswrite(ProjectSPECbase,ED_name_b,'EXT_DOORS','A4');
% xlswrite(ProjectSPECbase,ID_name_b,'INT_DOORS','A4');

% for MAC:
writecell(F_name_b,ProjectSPECbase,'sheet','FOUNDATIONS','range','A4');
writecell(GF_name_b,ProjectSPECbase,'sheet','GROUND_FLOORS','range','A4')
;
writecell(UF_name_b,ProjectSPECbase,'sheet','UPPER_FLOORS','range','A4');
writecell(R_name_b,ProjectSPECbase,'sheet','ROOF','range','A4');
writecell(EW_name_b,ProjectSPECbase,'sheet','EXT_WALLS-1','range','A4');
if T_EW ~= 1
    % xlswrite(ProjectSPECbase,EW2_name_b,'EXT_WALLS-2','A4');
    writecell(EW2_name_b,ProjectSPECbase,'sheet','EXT_WALLS-
2','range','A4');
    if T_EW == 3
        % xlswrite(ProjectSPECbase,EW3_name_b,'EXT_WALLS-3','A4');
        writecell(EW3_name_b,ProjectSPECbase,'sheet','EXT_WALLS-
3','range','A4');
    end
end
writecell(PW_name_b,ProjectSPECbase,'sheet','PAR_WALLS-1','range','A4');
if B_T == 5
    % xlswrite(ProjectSPECbase,PW_name_b2,'PAR_WALLS-2','A4'); % windows
    writecell(PW2_name_b,ProjectSPECbase,'sheet','PAR_WALLS-
2','range','A4'); % for mac
end

writecell(IW_name_b,ProjectSPECbase,'sheet','INT_WALLS','range','A4');
writecell(W_name_b,ProjectSPECbase,'sheet','WINDOWS','range','A4');
writecell(ED_name_b,ProjectSPECbase,'sheet','EXT_DOORS','range','A4');
writecell(ID_name_b,ProjectSPECbase,'sheet','INT_DOORS','range','A4');
```

DEFINE TYPE OF BUILDING ELEMENTS FOLLOWING NRM (set by RICS):
3.1. Substructure:
      3.1.1. Standard Foundation
      3.1.2. Lowest Floor Construction
      3.1.3. Basement retaining walls (not in use)

3.2. Superstructure:
        3.2.1. Upper Floors
        3.2.2. Roof
        3.2.3. External Walls
        3.2.4. Windows and External Doors
        3.2.5. Internal Walls and Partitions
        3.2.6. Internal Doors
3.3. Internal Finishes:
        3.3.1. Wall finishes
        3.3.2. Floor finishes
        3.3.3. Ceiling finishes

(3.1) Substructure Definition

3.1.1. Substructure-Standard Foundation (FO)

```
clc;
% fprintf('<a href="">3.2. DEFINING THE SUPERSTRUCTURE</a>\n'); %
hyperlink
% disp('Hello, <strong>World</strong>!'); % bold
disp '<strong>3.1. DEFINING THE UNDERSTRUCTURE</strong>';
disp ' ';
% Run Foundation definition program:
run BASE_FO


% DEFINE COMPARISON OPTIONS FOR FOUNDATIONS
% Comparison will be only available for different typology options
% run TF_comparison
```

3.1.2. Substructure-Lowest Floor (GROUND FLOOR-GF)

```
clc;
% Run Gorund Floor definition program:
run BASE_GF


% DEFINE COMPARISON OPTIONS FOR LOWEST FLOOR:...
% Comparison will be only available for different INSULATION & FINISHES
% run TGF_comparison
```

(3.2) Superstructure definition:

3.2.1. Upper Floors

Run Upper Floor definition program:

```
clc;
disp '<strong>3.2. DEFINING THE SUPERSTRUCTURE</strong>';
disp ' ';
run BASE_UF


% DEFINE COMPARISON OPTIONS FOR UPPER FLOOR:
% Comparison will be only available for different insulation options
```

293

```
% run TUF_comparison
```

3.2.2. Roofs: Pitched or Flat Roofs

Run Roof definition program:

```
clc;
run BASE_ROOF

% DEFINE COMPARISON OPTIONS FOR ROOF:
% Comparison will be only available for different finishes and insulation
options
% run TRF_comparison
```

3.2.3. Superstructure-External Wall (EW)

Define structural part of external walls:

```
clc;
run BASE_EW1_UK
run 'BASE_EW1_Finish';

if T_EW ~= 1
    run BASE_EW2_UK
    run 'BASE_EW2_Finish';
    if T_EW == 3
    run BASE_EW3_UK
    run 'BASE_EW3_Finish';
    end
end

% DEFINE COMPARISON OPTIONS FOR EXTERNAL WALLS
% Comparison will be only available for different insulation options
% Code is also done for different finishes options. Unavailable by now.
% run TEW_comparison
```

3.2.4 Superstructure-Internal Wall (IW)

Run Internal Wall definition program:

```
clc;
run BASE_IW

% DEFINE COMPARISON OPTIONS FOR INTERNAL WALLS
% Comparison will be only available for different insulation options
% Code is also done for different finishes options but Unavailable by
now.
% run TIW_comparison
```

3.2.5. Partition Walls (PW)

Run Partition Wall definition program:

```
clc;
if B_T ~= 4
    run BASE_PW1
    if B_T == 5 % this means we have a multistorey building
        run BASE_PW2
    end
end


% DEFINE COMPARISON OPTIONS FOR PARTITION WALLS
% Comparison will be only available for different insulation options
% Code is also done for different finishes options but Unavailable by
now.
%run TPW_comparison
```

3.2.6. Windows:

```
clc;
run BASE_WIN
```

3.2.7. External door:

```
clc;
run BASE_EXD
```

3.2.8. Internal Door Definition:

```
run BASE_IND


% DEFINE COMPARISON OPTIONS FOR INTERNAL WALLS
% Comparison will be only available for different insulation options
% Code is also done for different finishes options but Unavailable by
now.

%run TIW_comparison (not available at the moment)
```

(3.3) Internal Finishes Definition:

```
clc;
disp '<strong>3.3. DEFINING THE INTERNAL FINISHES</strong>';
disp ' ';
```

3.3.1. Internal Wall Finish definition program:

```
run 'BASE_IW_Finish';
```

3.3.2. Floor finishes:

```
clc;
run 'BASE_FLOOR_Finish';
```

3.3.3. Ceiling finishes:

```
clc;
run 'BASE_CEILING_Finish';
```

(3.4) Creating the variables from the construction elements defined

FOUNDATION-BASELINE "F_B" WITH ALL THE PARAMETERS SELECTED:

```
F_B = [F_B_CORE; subtotal];

% Read the projectSPECbase excel in order to operate with it
specfobnum=cell2mat(F_B(1:end-2,3:9));
[fob,fob2] = size(specfobnum);

% Write FOUNDATION into the ProjectSPECbase excel:
% for windows:
% xlswrite(ProjectSPECbase,F_B(:,1:end-1),'FOUNDATIONS','B4');
% xlswrite(ProjectSPECbase,F_B(:,end),'FOUNDATIONS','AD4');

% for MAC:
writecell(F_B(:,1:end-
1),ProjectSPECbase,'sheet','FOUNDATIONS','Range','B4');
writecell(F_B(:,end),ProjectSPECbase,'sheet','FOUNDATIONS','Range','AD4')
;
```

GROUND FLOOR - BASELINE WITH ALL THE PARAMETERS SELECTED:

```
if TGF_B == 1
    GF_B = [BASE_Floor_finish; GF_B_CORE; subtotal];
else
    GF_B = [BASE_Floor_finish; GF_B_INS; GF_B_CORE; subtotal];
end

% Read the projectSPECbase excel in order to operate with it
specgfbnum = cell2mat(GF_B(1:end-2,3:9));
[gfb,gfb2] = size(specgfbnum);

% Write GROUND FLOOR into the ProjectSPECbase excel:
% For windows:
% xlswrite(ProjectSPECbase,GF_B(:,1:end-1),'GROUND_FLOORS','B4');
% xlswrite(ProjectSPECbase,GF_B(:,end),'GROUND_FLOORS','AD4');

% For Mac:
writecell(GF_B(:,1:end-
1),ProjectSPECbase,'sheet','GROUND_FLOORS','range','B4');
writecell(GF_B(:,end),ProjectSPECbase,'sheet','GROUND_FLOORS','range','AD
4');
```

UPPER FLOOR - BASELINE WITH ALL THE PARAMETERS SELECTED:

```
UF_B = [BASE_Floor_finish; UF_B_CORE; CF_B_finish; subtotal];
```

```
% Read the projectSPECbase excel in order to operate with it
specufbnum = cell2mat(UF_B(1:end-2,3:9));
[ufb,ufb2] = size(specufbnum);

% Insulation options are not available by now
% if TUF_B == 1
%     BASE_UF = [BASE_Floor_finish; UF_B_CORE; CF_B_finish; subtotal];
% elseif TUF_B == 2
%     BASE_UF = [BASE_Floor_finish; UF_B_CORE; UF_B_INS; CF_B_finish;
subtotal];
% end

% Write UPPER FLOOR into the ProjectSPECbase excel:
writecell(UF_B(:,1:end-
1),ProjectSPECbase,'sheet','UPPER_FLOORS','range','B4');
writecell(UF_B(:,end),ProjectSPECbase,'sheet','UPPER_FLOORS','range','AD4
');
```

ROOF - BASELINE WITH ALL THE PARAMETERS SELECTED:

```
if TR_B == 2
    ROOF_B = [R_B_finish; R_B_INS; R_B_CORE; CF_B_finish; subtotal];
else
    ROOF_B = [R_B_finish; R_B_CORE; CF_B_finish; subtotal];
end

% Read the projectSPECbase excel in order to operate with it
specroofbnum = cell2mat(ROOF_B(1:end-2,3:9));
[rb,rb2] = size(specroofbnum);

% Write ROOF into the ProjectSPECbase excel:
writecell(ROOF_B(:,1:end-1),ProjectSPECbase,'sheet','ROOF','range','B4');
writecell(ROOF_B(:,end),ProjectSPECbase,'sheet','ROOF','range','AD4');
```

EXTERNAL WALL - BASELINE WITH ALL PARAMETRES SELECTED

```
run SPEC_EW1_B

if T_EW ~= 1 % this means two diferent external walls are defined.
    run SPEC_EW2_B
    if T_EW == 3 % this means three diferent external walls are defined.
        run SPEC_EW3_B
    end
end
```

DEFINING WINDOWS "WIN_B" AND EXTERNAL DOORS "EXD_B" BASELINE:

```
WIN_B = [TWIN_B_CORE; subtotal];

% Read the excel & get row numbers in order to operate with it
specwinbnum = cell2mat(WIN_B(1:end-2,3:9));
```

```
[wb,wb2] = size(specwinbnum);

% Write info into the projectSPECbase excel:
writecell(WIN_B(:,1:end-
1),ProjectSPECbase,'sheet','WINDOWS','range','B4');
writecell(WIN_B(:,end),ProjectSPECbase,'sheet','WINDOWS','range','AD4');
```

External Doors

```
EXD_B = [TEXD_B_CORE; subtotal];

% Read the projectSPECbase excel in order to operate with it
specexdbnum = cell2mat(EXD_B(1:end-2,3:9));
[edob,edob2] = size(specexdbnum);

% Write DOORS into the projectSPECbase excel:
writecell(EXD_B(:,1:end-
1),ProjectSPECbase,'sheet','EXT_DOORS','range','B4');
writecell(EXD_B(:,end),ProjectSPECbase,'sheet','EXT_DOORS','range','AD4')
;
```

DEFINING INTERNAL WALL WITH ALL THE PARAMETERS SELCTED:

```
if TIW_B == 1
    IW_B = [IW_B_finish; PLAST_3; IW_B_CORE;  PLAST_3; IW_B_finish;
subtotal];
else
    IW_B = [IW_B_finish; PLAST_3; IW_B_INS; IW_B_CORE; IW_B_INS; PLAST_3;
IW_B_finish; subtotal];
end

% Read the projectSPECbase excel in order to operate with it
speciwbnum = cell2mat(IW_B(1:end-2,3:9));
[iwb,iwb2] = size(speciwbnum);

% Write INTERNAL WALL into the ProjectSPECbase excel:
writecell(IW_B(:,1:end-
1),ProjectSPECbase,'sheet','INT_WALLS','range','B4');
writecell(IW_B(:,end),ProjectSPECbase,'sheet','INT_WALLS','range','AD4');
```

DEFINING PARTITION WALL WITH ALL THE PARAMETERS SELCTED:

```
if B_T ~= 4
    run SPEC_PW1_B
    if B_T == 5
        run SPEC_PW2_B
    end
end
```

Defining Internal doors

```
IND_B = [TIND_B_CORE; subtotal];
```

```
% Read the projectSPECbase excel in order to operate with it
specindbnum = cell2mat(IND_B(1:end-2,3:9));
[idob,idob2] = size(specindbnum);

% Write DOORS into the projectSPECbase excel:
writecell(IND_B(:,1:end-
1),ProjectSPECbase,'sheet','INT_DOORS','range','B4');
writecell(IND_B(:,end),ProjectSPECbase,'sheet','INT_DOORS','range','AA4')
;
```

(3.5) Execute the project environmental data program to continue

```
save(FILE_SPEC_NAME);

disp 'MOVE TO NEXT SECTION? ';
disp ' ';
CONTINUE_ENV=input('Do you want to continue with the Environmental
calculations?(Y/N): ','s');
if CONTINUE_ENV(1,1) == 'Y'
        run ADProjectEnvirData2004Mac;
else
    disp ' ';
    disp ' ';
    disp ' ';
    disp ' ';
    disp 'Thank you for using 2020©CRC Specific DB Program.';
    disp ' ';
    disp 'The Building environmental information has been saved in
"3_ProjectSPECbase.xlsx"';
    fprintf ('All variables have also been saved in
"%s"',FILE_SPEC_NAME);
    % disp 'If you decided to compare with other options:';
    % disp 'The Building Scenario 2 information has been saved in
"3_ProjectSPECop1.xlsx"';
    % disp 'The Building Scenario 3 information has been saved in
"3_ProjectSPECop2.xlsx"';
    disp ' ';
end
```

The second main program file finishes here. All program files that are executed automatically within it are highlighted on yellow and they will be shown below

(3.1.1.p) BASE_FO - Foundation program file

```
disp '3.1.1. DEFINING THE FOUNDATION OF THE PROJECT: BASELINE';
disp ' ';
disp '(1) Concrete Raft 500/300mm (Default option)';
disp '(2) Concrete Strip 600x400mm + Compacted gravel 500mm';
disp '(3) RAVENSCRAIG Concrete Raft 600/300mm';
disp '(4) RAVENSCRAIG Concrete Strips 600x400mm + Compacted gravel';
disp '(5) YOKER Concrete Strip 600x600/1000mm + Compacted gravel 250mm +
insulation 150mm';
disp '(6) YOKER Concrete Raft with Concrete Piles (diam 750mm)';
TF_B=input('Please define the type of foundation: ');
disp ' ';

if TF_B == 1
    disp 'Type of Foundation selected is "Concrete Raft 500/300mm".';
    F_B_CORE = [CON_1; CLAY_5; CLAY_6];
elseif TF_B ==2
    disp 'Type of Foundation selected is "Concrete Strips 600x400mm +
Compacted Gravel 500mm".';
    F_B_CORE = [CON_2; OTHER_7; CLAY_5; CLAY_6];
elseif TF_B ==3
    disp 'Type of Foundation selected is "RAVENSCRAIG Concrete Raft
600/300mm';
    F_B_CORE = [CON_7_B; OTHER_1; CLAY_5; CLAY_6];
elseif TF_B ==4
    disp 'Type of Foundation selected is "RAVENSCRAIG Concrete Strips
600x400mm';
    F_B_CORE = [CON_7_A; OTHER_1; OTHER_7; CLAY_5; CLAY_6];
elseif TF_B ==5
    disp 'Type of Foundation selected is "YOKER Concrete Strip
600x600/1000mm + Compacted gravel 250mm + insulation 150mm".';
    F_B_CORE = [CON_8; OTHER_8; INS_5E; OTHER_1; CON_12];
elseif TF_B ==6
    disp 'Type of Foundation selected is "YOKER Concrete Raft + Concrete
Piles + insulation 150mm".';
    F_B_CORE = [CON_9; INS_5E; OTHER_1; CON_12];
else
    disp 'Type of Foundation is not properly defined';
    disp 'By default "Concrete Raft 500/300mm" is selected';
    TF_B = 1;
    F_B_CORE = [CON_1; CLAY_5; CLAY_6];
end
disp ' ';
disp ' ';
```

(3.1.2.p) BASE_GF - Ground Floor program file

```
disp '3.1.2. DEFINING THE GROUND FLOOR OF THE PROJECT: BASELINE';
disp 'If your Ground Floor is not defined type "0". Thank you. ';
disp ' ';
disp '(1) Not Insulated (default option)';
disp '(2) Thermally Insulated';
TGF_B=input('Please define the type of Ground Floor: ');
disp ' ';
if TGF_B == 1
    disp 'Please be aware that this option might not be compliant with
current building regulations';
elseif TGF_B == 2
    run 'TGF_B_Ins';
else
    disp 'Type of Ground Floor is not defined properly.';
    disp 'By default "Not insulated" option is selected';
    TGF_B = 1;
    disp 'Please be aware that this option might not be compliant with
current building regulations';
end
disp ' ';
disp '(1) Timber I-Joists h=250mm @400mm (default option)';
disp '(2) Pre-cast Concrete Joists h=250mm';
disp '(3) Yoker Reinforced concrete slab h=175mm';
TGF_B_CORE=input('Please select the material used for the GF: ');
disp ' ';
% Then Make the same as previously but within each option.
if TGF_B_CORE == 1
    % For Timber I-Joists selection.
    disp 'Type of Structure selected is "Timber I-Joist @ 400mm".';
    GF_B_CORE = [TIMBER_1; TIMBER_6];
elseif TGF_B_CORE == 2
    % For Pre-cast concrete joists.
    disp 'Type of Structure selected is "Pre-cast concrete Joists @
600mm".';
    GF_B_CORE = [TIMBER_1; CON_3];

elseif TGF_B_CORE == 3
    % For Pre-cast concrete joists.
    disp 'Type of Structure selected is "Yoker Concrete Slab d=175mm"';
    GF_B_CORE = CON_9;
else
    disp 'Type of Structure for Ground Floor is not properly defined';
    disp 'By default "Timber I-Joist @ 400mm" is selected';
    TGF_B_CORE = 1;
    GF_B_CORE = [TIMBER_1; TIMBER_6];
end
```

(3.2.1.1.p) TGF_B_Ins – Ground floor Insulation options program file

```matlab
% TYPE OF INSULATION FOR GROUND FLOOR: BASELINE
disp ' ';
disp '(1) WOOD FIBRE';
disp '(2) MINERAL FIBRE';
disp '(3) EXPANDED POLYSTYRENE';
GF_B_INS_M=input('PLEASE SELECT TYPE OF INSULATION?: ');
disp ' ';
disp '(A) 100mm';
disp '(B) 150mm';
disp '(C) 200mm';
disp '(D) 50mm';
disp ' ';
ThGF_B_INS=input('PLEASE SELECT THE THICKNESS OF THE INSULATION?:
','s');
if GF_B_INS_M(1,1) == 1
    if ThGF_B_INS == 'A'
        GF_B_INS = INS_2A;
    elseif ThGF_B_INS == 'B'
        GF_B_INS = INS_2B;
    elseif ThGF_B_INS == 'C'
        GF_B_INS = INS_2C;
    else
        GF_B_INS = INS_2D;
    end
elseif GF_B_INS_M(1,1) == 2
    if ThGF_B_INS == 'A'
        GF_B_INS = INS_1A;
    elseif ThGF_B_INS == 'B'
        GF_B_INS = INS_1B;
    elseif ThGF_B_INS == 'C'
        GF_B_INS = INS_1C;
    else
        GF_B_INS = INS_1D;
    end
else
    if ThGF_B_INS == 'A'
        GF_B_INS = INS_5A;
    elseif ThGF_B_INS == 'B'
        GF_B_INS = INS_5B;
    elseif ThGF_B_INS == 'C'
        GF_B_INS = INS_5C;
    elseif ThGF_B_INS == 'D'
        GF_B_INS = INS_5D;
    end
end
```

(3.2.1.p) BASE_UF - Upper Floor program file

```
 disp '3.2.1. DEFINING THE UPPER FLOOR(S) OF THE PROJECT: BASELINE';
 disp ' ';
```

UPPER FLOOR HAS NOT INSULATION OPTIONS AS IS NOT LIKELY TO HAVE IT.

```
    disp '(1) Timber I-Joists @400mm (default option)';
    disp '(2) Pre-cast Concrete Joists @600mm';
    disp '(3) Yoker Cross Laminated Timber (CLT) flats';
    disp '(4) Yoker Cross Laminated Timber (CLT) common areas';
    disp '(5) Metal Double-t joists @600mm (Not available)';
    disp ' ';
    TUF_B_CORE=input('Please define the Upper floor structure material:
');
    disp ' ';
    disp ' ';
    % Then select the core of the upper floors.
    if TUF_B_CORE == 1
        % For Timber I-Joists selection.
        disp 'Type of Structure selected is "Timber I-Joist @ 400mm".';
        UF_B_CORE = [TIMBER_1; TIMBER_6];
    elseif TUF_B_CORE == 2
        % For Pre-cast concrete joists.
        disp 'Type of Structure selected is "Pre-cast concrete Joists @
600mm".';
        UF_B_CORE = [TIMBER_1; CON_3];
    elseif TUF_B_CORE == 3
        % For CLT panels for floor structure.
        disp 'Type of Structure selected is "Yoker Cross Laminated
Timber CLT floor" flats.';
        UF_B_CORE = [PLAST_3; INS_1E; TIMBER_10; PLAST_3; PLAST_3;
INS_1D];
    elseif TUF_B_CORE == 4
        % For CLT panels for floor structure.
        disp 'Type of Structure selected is "Yoker Cross Laminated
Timber CLT floor" close.';
        UF_B_CORE = [CON_10; INS_1E; TIMBER_10; PLAST_3; PLAST_3;
INS_1D];
    else
        disp 'Type of Structure material for Upper Floor is not properly
defined';
        disp 'By default "Timber I-Joist @ 400mm" is selected';
        UF_B_CORE = [TIMBER_1; TIMBER_6];
    end
    disp ' ';
 % end
```

(3.2.2.p) BASE_ROOF - Roof program file

```
disp '3.2.2. DEFINING THE ROOF OF THE PROJECT: BASELINE';
disp ' ';
disp '(1) Not insulated (default option)';
disp '(2) Thermally Insulated';
TR_B=input('Please define type of Roof-baseline: ');
disp ' ';
if TR_B == 2
    run TRF_B_Ins
else
    disp 'Please be aware that this option may not be compliant with
current regulations';
end

if B_TR == 2
% Flat Roof
    disp 'Type of Roof selected is Flat Roof';
    disp 'Ceiling finish is assumed to be plasterboard and general paint
(2 coats)';
    disp ' ';
    disp '(1) Timber I-Joists @400mm (default option)';
    disp '(2) Pre-cast Concrete Joists @600mm';
    disp '(3) Yoker Cross Laminated Timber - CLT floors';
    disp '(5) Metal Double-t joists @600mm (Not available)';
    TR_B_CORE=input('Please define the Flat Roof structure material: ');
    disp ' ';
    disp ' ';
    if TR_B_CORE == 1
        R_B_CORE = [OTHER_1; TIMBER_1; TIMBER_6];
    elseif TR_B_CORE == 2
        R_B_CORE = [OTHER_1; TIMBER_1; CON_3];
    elseif TR_B_CORE == 3
        R_B_CORE = [TIMBER_10; PLAST_3; PLAST_3; INS_1D];
    else
        TR_B_CORE = 1;
        R_B_CORE = [OTHER_1; TIMBER_1; TIMBER_6];
    end


elseif B_TR == 1
    disp '(1) Timber Truss @ 450mm (default option)';
    disp '(N/A) Metal Truss for pitched roof is not currently
available';
    disp '(N/A) Brick Walls for pitched roof is not currently
available';
    TR_B_CORE=input('Please define the Pitched Roof structure material:
');
    disp ' ';
    disp ' ';
```

304

```
    if TR_B_CORE == 1  % Timber Truss selected.
        if B_TR_T == 30
            disp 'Type of Structure selected is "Timber truss @
450mm".';
            R_B_CORE = [OTHER_1; TIMBER_1; TIMBER_7];
        else
            disp 'Only Timber Truss with 30degrees inclination are
available';
            R_B_CORE = [OTHER_1; TIMBER_1; TIMBER_7];
        end
    else
        disp 'Type of Structure for Roof is not properly defined';
        disp 'By default "Timber Truss @ 450mm" is selected';
        disp ' ';
        disp ' ';
        R_B_CORE = [OTHER_1; TIMBER_1; TIMBER_7];
    end
 else
    disp 'Type of Structure for Roof is not properly defined';
    disp 'By default "Timber Truss @ 450mm" is selected';
    disp ' ';
    disp ' ';
    R_B_CORE = [OTHER_1; TIMBER_1; TIMBER_7];
 end
 run BASE_ROOF_Finish
```

Programs that will be automatically executed are highlighted in blue, correspongding with the Roof insulation options and the Roof external finish. Both program files are shown below:

(3.2.2.1.p) TRF_B_Ins – Roof Insulation options program file

```matlab
% TYPE OF INSULATION FOR ROOF: BASELINE

disp 'Insulation options:'
disp ' ';
disp '(1) WOOD FIBRE';
disp '(2) MINERAL FIBRE';
disp '(3) EXPANDED POLYSTYRENE (default option)';
disp ' ';
R_B_INS_M=input('Please select type of insulation: ');
disp ' ';
disp 'Thickness: 100mm(A), 150mm(B), 170mm(C) or 200mm(D) ';
disp ' ';
ThR_B_INS=input('Please select the insulation thickness?: ','s');

if R_B_INS_M(1,1) == 1
    if ThR_B_INS == 'A'
        R_B_INS = INS_2A;
    elseif ThR_B_INS == 'B'
        R_B_INS = INS_2B;
    else
        R_B_INS = INS_2C;
    end
elseif R_B_INS_M(1,1) == 2
    if ThR_B_INS == 'A'
        R_B_INS = INS_3A;
    elseif ThR_B_INS == 'B'
        R_B_INS = INS_3B;
    elseif ThR_B_INS == 'D'
        R_B_INS = INS_3C;
    else
        R_B_INS = INS_3A;
    end
else
    if ThR_B_INS == 'A'
        R_B_INS = INS_5A;
    elseif ThR_B_INS == 'B'
        R_B_INS = INS_5B;
    elseif ThR_B_INS == 'C'
        R_B_INS = INS_5F;
    elseif ThR_B_INS == 'D'
        R_B_INS = INS_5C;
    else
        R_B_INS = INS_5A;
    end
end
disp ' ';
```

(3.2.2.2.p) BASE_ROOF_Finish – Roof external finish program file

```
 disp ' ';
 disp 'TYPE OF ROOF FINISH SELECTION:';
 disp ' ';
 fprintf('Type of Roof selected is "%s".',ROOF_NAME);
 disp ' ';
 disp '(1) Slate tiles (default option)';
 disp '(2) Clay tiles';
 disp '(3) Roof underlay 3mm + membrane 3mm';
 disp '(4) Terrazzo tiles for technical floor'; % not available now
 disp ' ';
 TR_B_finish=input('Please define the Roof covering material: ');

 if TR_B_finish == 1
     disp ' ';
     disp ' ';
     disp 'The type of Roof cover selected is Slate Tiles';
     R_B_finish = FIN_9;

 elseif TR_B_finish == 2
     disp ' ';
     disp ' ';
     disp 'The type of Roof cover selected is Clay Tiles';
     R_B_finish = CLAY_3;
 elseif TR_B_finish == 3
     disp ' ';
     disp ' ';
     disp 'The type of Roof cover selected is Roof membrane with
underlay';
     R_B_finish = [OTHER_1;OTHER_1]; % to revise!
 elseif TR_B_finish == 4
     disp ' ';
     disp ' ';
     disp 'The type of Roof cover selected is Stone Tiles';
     R_B_finish = STONE_1; % to revise!
 else
     disp ' ';
     disp ' ';
     disp 'Roof cover is not properly defined';
     disp 'By default "Slate tiles" will be selected';
     R_B_finish = FIN_9;
 end
```

(3.2.3) External Wall definition:

(3.2.3.1.p) BASE_EW1_UK - External wall 1 program file

```
% Open pdf file with graphic options for external walls:

% for WINDOWS:
% winopen ('EW_options.pdf');

% for MAC
open ('EW_options.pdf');
```

Define type of External wall 1 (EW-1):

```
disp '3.2.3.1. DEFINING THE EXTERNAL WALLS - 1';
disp ' ';
disp '(1) Not Insulated (default option)';
disp '(2) Externally Insulated';
disp '(3) Internally Insulated';
TEW_B=input('Please define the type of external wall-1: ');
disp ' ';

if TEW_B > 1
    run 'TEW1_B_Ins';
else
    disp 'You are selecting an External Wall without Insulation.';
    disp 'This might not be compliant with current Building
Regulations';
    disp ' ';
    disp ' ';
    TEW_B = 1;
    EW_B_INS_N = 'NO_INS'; % This is for the results file name only
end
```

Define Cavity space treatment:

```
TEW_B_CAV=input('Is there any insulation in the Cavity space: (Y/N)?
','s');
disp ' ';
if TEW_B_CAV == 'N'
    EW_B_CAV = OTHER_6;
    EW_B_CAV_N = 'AIR'; % This is for the results file name only
elseif TEW_B_CAV == 'Y'
    run 'TEW1_B_CAV_Ins';
    EW_B_CAV = EW_B_CAV_INS;
else
    disp 'Cavity space is not properly defined';
    disp 'By default "No insulation" is selected';
    EW_B_CAV = OTHER_6;
    EW_B_CAV_N = 'AIR'; % This is for the results file name only
end
```

```
 disp ' ';
```

Defining the external leaf of the EW-1:

```
 disp '(1) Single brick wall d=102,5mm (default option)';
 disp '(2) Double brick wall d=215mm';
 disp '(3) Concrete block wall d=100mm';
 disp '(4) Concrete block wall d=200mm';
 disp '(5) Timber studs 100x150mm @600mm';
 disp '(6) Cross Laminated Timber CLT d(avergae)=116mm';
 disp '(7) Light metal studs 70x50mm @600mm';
% disp '(8) Brick wall d=290mm';
% disp '(9) Brick wall d=330mm';
% disp '(10) Brick wall d=380mm';
 TEW_B_EXT=input('Please define material for the external leaf of EW-1:
');
 disp ' ';
% Then Make the same as previously but within each option.
 if TEW_B_EXT == 1
     disp 'Type of EW-External leaf selected is "UK Single Brick Wall
d=102,5mm".';
     disp ' ';
     EW_B_CORE_EXT = CLAY_1;
     EW_B_CORE_EXT_N = 'BRICK'; % This is for the results file name only

 elseif TEW_B_EXT == 2
     disp 'Type of EW-External leaf selected is "UK Double Brick Wall
d=215mm".';
     disp ' ';
     EW_B_CORE_EXT = CLAY_2;
     EW_B_CORE_EXT_N = 'BRICK'; % This is for the results file name only

 elseif TEW_B_EXT == 3
     disp 'Type of EW-External leaf selected is "Concrete block wall
d=100mm".';
     disp ' ';
     EW_B_CORE_EXT = CON_4;
     EW_B_CORE_EXT_N = 'CON'; % This is for the results file name only

 elseif TEW_B_EXT == 4
     disp 'Type of EW-External leaf selected is "Concrete block wall
d=200mm".';
     disp ' ';
     EW_B_CORE_EXT = CON_5;
     EW_B_CORE_EXT_N = 'CON'; % This is for the results file name only

 elseif TEW_B_EXT == 5
     disp 'Type of EW-External leaf selected is "Timber studs wall".';
     disp ' ';
     EW_B_CORE_EXT = TIMBER_13;
```

```
    EW_B_CORE_EXT_N = 'TIMB'; % This is for the results file name only

 elseif TEW_B_EXT == 6
     disp 'Type of EW-External leaf selected is "CLT Wall".';
     disp ' ';
     EW_B_CORE_EXT = TIMBER_9;
     EW_B_CORE_EXT_N = 'CLT'; % This is for the results file name only

 elseif TEW_B_EXT == 7
     disp 'Type of EW-External leaf selected is "Metal Studs 70x50mm".';
     disp ' ';
     EW_B_CORE_EXT = PLAST_4;
     EW_B_CORE_EXT_N = 'M_STUDS'; % This is for the results file name
only

 else
     disp 'External leaf of EW-1 is not properly defined';
     disp 'By default "Single Brick Wall" is selected';
     EW_B_CORE_EXT = [MOR_6; CLAY_1];
     EW_B_CORE_EXT_N = 'BRICK'; % This is for the results file name only
 end
```

Defining the internal leaf for EW-1:

```
 disp ' ';
 disp '(1) Single brick wall d=102,5mm (default option)';
 disp '(2) Concrete block wall d=100mm';
 disp '(3) Timber studs 100x150mm @600mm';
 disp '(4) Cross Laminated Timber CLT d(avergae)=116mm';
 disp '(5) Light metal studs 70x50mm @600mm';
 disp '(6) Light metal studs 50x50mm @600mm';
 disp '(0) There is not internal leaf';
 TEW_B_INT=input('Please define material for the internal leaf of EW: ');
 disp ' ';
 if TEW_B_INT == 1
     disp 'Type of EW-Internal leaf selected is "UK Single Brick Wall
d=102,5mm".';
     EW_B_CORE_INT = [CLAY_1; MOR_6; PLAST_3];
     EW_B_CORE_INT_N = 'BRICK';

 elseif TEW_B_INT == 2
     disp 'Type of EW-Internal leaf selected is "Concrete Block Wall
d=100mm".';
     EW_B_CORE_INT = [CON_4; MOR_6; PLAST_3];
     EW_B_CORE_INT_N = 'CON';

 elseif TEW_B_INT == 3
     disp 'Type of EW-Internal leaf selected is "Timber studs wall".';
     EW_B_CORE_INT = [TIMBER_13; PLAST_3];
     EW_B_CORE_INT_N = 'TIMB';
```

```
 elseif TEW_B_INT == 4
     disp 'Type of EW-Internal leaf selected is "CLT Wall".';
     EW_B_CORE_INT = [TIMBER_9; PLAST_5; PLAST_3];
     EW_B_CORE_INT_N = 'CLT';

 elseif TEW_B_INT == 5
     disp 'Type of External Wall selected is "Metal Studs Wall
70x50mm".';
     EW_B_CORE_INT = [PLAST_4; PLAST_3];
     EW_B_CORE_INT_N = 'M_STUDS';

 elseif TEW_B_INT == 6
     disp 'Type of External Wall selected is "Metal Studs Wall
50x50mm".';
     EW_B_CORE_INT = [PLAST_5; PLAST_3];
     EW_B_CORE_INT_N = 'M_STUDS';

 elseif TEW_B_INT == 0
     EW_B_CORE_INT = OTHER_6;
     EW_B_CORE_INT_N = 'AIR';

 else
     disp 'Internal leaf of EW is not properly defined';
     disp 'By default "Single Brick Wall" is selected';
     EW_B_CORE_INT = [CLAY_1;MOR_6];
     EW_B_CORE_INT_N = 'BRICK';
 end
 disp ' ';
```

When defining the external wall 1, other programs for insulation definition (if selected) will be executed. The same happens for external wall 2 and 3 definition program files, in case there are more than one type of external wall.

In order to not to make this appendix even more extensive, programs files for BASE_EW2 and BASE_EW3 are not shown since the only difference between this one and them is that the words "EW1" are replaced by "EW2" or "EW3" respectively, including the insulation options programs.

(3.2.3.2.p) BASE_EW1_FINISH - External wall 1 finish program file

```
disp '3.2.3.2. Defining External Wall-1 finish';
disp ' ';
disp '(1) Render+Paint (default option)';
disp '(2) Ceramic cladding (Brick slip)';
disp '(3) HPL panel cladding';
disp '(4) Vinyl brick slip cladding';
disp '(5) No finish';
TEW_B_EXT_finish=input('Please select External Finish for EXTERNAL WALL-
1: ');

if TEW_B_EXT_finish == 1
    disp ' ';
    disp 'The external Finish selected is Render and General Paint';
    EW_B_EXT_finish = [FIN_2; MOR_3];

elseif TEW_B_EXT_finish == 2
    disp ' ';
    disp 'The external Finish selected is Ceramic Cladding';
    EW_B_EXT_finish = [CLAY_3; MOR_3];

elseif TEW_B_EXT_finish == 3
    disp ' ';
    disp 'The external Finish selected is HPL panel Cladding';
    EW_B_EXT_finish = [TIMBER_14; PLAST_4];

elseif TEW_B_EXT_finish == 4
    disp ' ';
    disp 'The external Finish selected is vinyl brick slip Cladding';
    EW_B_EXT_finish = [FIN_10; OTHER_9];
elseif TEW_B_EXT_finish == 5
    disp ' ';
    disp 'The external Finish selected is "no finish"';
    EW_B_EXT_finish = OTHER_6;
else
    disp ' ';
    disp 'The external Finish selected is not properly defined';
    disp 'By default "Render+Paint" is selected';
    EW_B_EXT_finish = [FIN_2; MOR_3];
end
```

(3.2.3.1.1.p) TEW1_B_Ins – External Wall 1 Insulation program file

```matlab
% TYPE OF EW1 INSULATION: BASELINE
disp 'Insulation options: WOOD FIBRE(1), MINERAL FIBRE(2) OR EXPANDED
POLYSTYRENE(3) ';
disp ' ';
TEW_B_INS=input('PLEASE SELECT TYPE OF INSULATION?: ');
disp ' ';
disp 'Thickness: 100mm(A), 150mm(B) OR 200mm(C) ';
disp ' ';
ThEW_B_INS=input('PLEASE SELECT THE THICKNESS OF THE INSULATION?:
','s');
if TEW_B_INS(1,1) == 1
    if ThEW_B_INS == 'A'
        EW_B_INS = INS_2A;
        EW_B_INS_N = 'INS_WF_100';
    elseif ThEW_B_INS == 'B'
        EW_B_INS = INS_2B;
        EW_B_INS_N = 'INS_WF_150';
    else
        EW_B_INS = INS_2C;
        EW_B_INS_N = 'INS_WF_200';
    end
elseif TEW_B_INS(1,1) == 2
    if ThEW_B_INS == 'A'
        EW_B_INS = INS_3A;
        EW_B_INS_N = 'INS_MF_100';
    elseif ThEW_B_INS == 'B'
        EW_B_INS = INS_3B;
        EW_B_INS_N = 'INS_MF_150';
    else
        EW_B_INS = INS_3C;
        EW_B_INS_N = 'INS_MF_200';
    end
else
    if ThEW_B_INS == 'A'
        EW_B_INS = INS_5A;
        EW_B_INS_N = 'INS_EP_100';
    elseif ThEW_B_INS == 'B'
        EW_B_INS = INS_5B;
        EW_B_INS_N = 'INS_EP_150';
    else
        EW_B_INS = INS_5C;
        EW_B_INS_N = 'INS_EP_200';
    end
end
```

(3.2.3.1.2.p) TEW1_B_CAV_Ins – External Wall 1 Cavity Insulation program file

```
disp 'WOOD FIBRE(1), MINERAL FIBRE(2) OR EXPANDED POLYSTYRENE(3) ';
disp 'Thickness constrained by the cavity space: 100mm ';
disp ' ';
TEW_B_CAV_INS=input('Please define the type of Cavity insulation
Material?: ');
if TEW_B_CAV_INS(1,1) == 1
    EW_B_CAV_INS = INS_2A;
    EW_B_CAV_N = 'AIR+WF'; % For file name only
elseif TEW_B_CAV_INS(1,1) == 2
    EW_B_CAV_INS = INS_3A;
    EW_B_CAV_N = 'AIR+MF'; % For file name only
else
    EW_B_CAV_INS = INS_5A;
    EW_B_CAV_N = 'AIR+EP'; % For file name only
end
```

(3.2.3.3.p) SPEC_EW1_B – External Wall 1 composition with variables program file

```
if TEW_B == 3
    EW_B = [EW_B_EXT_finish; EW_B_CORE_EXT; EW_B_CAV; EW_B_CORE_INT;
EW_B_INS; IW_B_finish; subtotal];
    EW_B_N =
[EW_B_INS_N,'__',EW_B_CORE_EXT_N,'__',EW_B_CAV_N,'__',EW_B_CORE_INT_N];
 elseif TEW_B == 2
    EW_B = [EW_B_EXT_finish; EW_B_INS; EW_B_CORE_EXT; EW_B_CAV;
EW_B_CORE_INT; IW_B_finish; subtotal];
    EW_B_N =
[EW_B_INS_N,'__',EW_B_CORE_EXT_N,'__',EW_B_CAV_N,'__',EW_B_CORE_INT_N];
 else
    EW_B = [EW_B_EXT_finish; EW_B_CORE_EXT; EW_B_CAV; EW_B_CORE_INT;
IW_B_finish; subtotal];
    EW_B_N =
[EW_B_INS_N,'__',EW_B_CORE_EXT_N,'__',EW_B_CAV_N,'__',EW_B_CORE_INT_N];
 end
% Read the projectSPECbase excel in order to operate with it
specewbnum = cell2mat(EW_B(1:end-2,3:9));
[ewb,ewb2] = size(specewbnum);
% Write EXTERNAL WALL OP2 into the ProjectSPECbase excel:
% FOR WINDOWS: no code for windows for this program
% FOR MAC:
writecell(EW_B(:,1:end-1),ProjectSPECbase,'sheet','EXT_WALLS-
1','range','B4');
writecell(EW_B(:,end),ProjectSPECbase,'sheet','EXT_WALLS-
1','range','AD4');
```

(3.2.4.p) BASE_IW - Internal Walls program file

```
disp '3.2.4. DEFINING THE INTERNAL WALLS OF THE PROJECT: BASELINE';
disp ' ';
disp '(1) Not Insulated (default option)';
disp '(2) Soundproof Insulated (Acoustic Soundblock Plasterboard)';
disp '(3) Thermally insulated 50mm Expanded Polystyrenne';
disp '(4) Both Thermally & Soundproof Insulated';
TIW_B=input('Please define the type of internal wall: ');
disp ' ';
if TIW_B == 2
    IW_B_INS = PLAST_3;

elseif TIW_B == 3
    IW_B_INS = INS_5D;

elseif TIW_B == 4
    IW_B_INS = [INS_5D; PLAST_3];
else
    if TIW_B == 1
        disp 'Type of Internal wall selected is not insulated';
        disp 'You are selecting Internal Wall without Insulation';
        disp ' ';
        disp ' ';
    else
    disp 'Type of Internal wall is not properly defined';
    disp 'Default option is Internal Wall without Insulation.';
    disp ' ';
    disp ' ';
    end
    TIW_B = 1;
    IW_B_INS_N = 'NO_INS'; % This is for the results file name only

end
disp ' ';
disp ' ';

% Defining the material used for the IW:
disp '(1) Single Brick Wall (d=102.5mm) (default option)';
disp '(2) Single Light Concrete Blocks (d=100mm)';
disp '(3) Yoker Cross Laminated Timber CLT walls';
disp '(4) Timber studs 150x50mm @600mm';
disp '(5) Light metal studs 70x50mm @600mm';
TIW_B_CORE=input('Please define the material used for internal wall: ');
disp ' ';
disp ' ';
% Defining the core of the IW based on selection:
if TIW_B_CORE == 1
    % For double brick wall selection.
    disp 'Material selected is "Single Brick Wall".';
```

```matlab
    IW_B_CORE = [MOR_6; CLAY_1; MOR_6];


elseif TIW_B_CORE == 2
    % For double concrete wall selection.
    disp 'Material selected is "Single Light Concrete Block Wall".';
    IW_B_CORE = [MOR_6; CON_4; MOR_6];
elseif TIW_B_CORE == 3
    % For Timber studs partition wall selection.
    disp 'Material selected is "CLT wall d=116mm".';
    IW_B_CORE = [PLAST_4; TIMBER_9; PLAST_4];
elseif TIW_B_CORE == 4
    % For Timber studs partition wall selection.
    disp 'Material selected is "Timber Studs Wall 150x50mm".';
    IW_B_CORE = TIMBER_13;
elseif TIW_B_CORE == 5
    % For Metal studs partition wall selection.
    disp 'Material selected is "Light Metal Studs Wall 70x50mm".';
    IW_B_CORE = PLAST_4;
else
    disp 'Type of Internal wall is not properly defined';
    disp 'By default "Single Brick Wall d=102.5mm" is selected';
    IW_B_CORE = [MOR_6; CLAY_1; MOR_6];
end
disp ' ';
disp ' ';
```

(3.2.5.p) Partition Walls definition:

(3.2.5.1) BASE_PW1 - Partition wall 1 program file

```
disp ' ';
disp '3.2.5.1. DEFINING THE PARTITION WALL - 1';
disp 'If your Partition Wall type is not defined type "0". Thank you. ';
disp ' ';
disp '(1) Not insulated (default option)';
disp '(2) Acoustically Insulated (Acoustic Soundblock Plasterboard)';
disp '(3) Thermally insulated 50mm Expanded Polystyrenne';
disp '(4) Both Thermally & Soundproof Insulated';
disp ' ';
TPW_B=input('Please define the type of PW-1: ');
disp ' ';
if TPW_B == 2
    PW_B_INS = PLAST_3;
elseif TPW_B == 3
    PW_B_INS = INS_5D;
elseif TPW_B == 4
    PW_B_INS = [PLAST_3; INS_5D];
else
    if TPW_B == 1
        disp 'You are selecting an Party Wall-1 without Insulation.';
    else
        disp 'Type of Party wall is not properly defined';
        disp 'By default, not insultaed option is selected';
        TPW_B = 1;
    end
        disp 'This might not be compliant with current Building
Regulations';
        disp ' ';
        disp ' ';
        PW_B_INS_N = 'NO_INS'; % This is for the results file name only
 end
disp ' ';
disp ' ';
```

Select type of structure material:

```
disp '(1) Duoble Brick Wall(d=215mm) (default option)';
disp '(2) Double Dense Concrete Blocks (d=200mm)';
disp '(3) Cross Laminated Timber CLT d=116mm with light metal battens';
disp '(4) Timber studs 150x50mm @600mm';
disp '(5) Light metal 70x50mm @600mm';
TPW_B_CORE=input('Please select the material used for PW-1: ');
disp ' ';
% Then define the core material used for partition walls:
if TPW_B_CORE == 1
    % For double brick wall selection.
    disp 'Material selected is "Double Brick Wall".';
```

```matlab
    PW_B_CORE = [MOR_6; CLAY_2; MOR_6];

elseif TPW_B_CORE == 2
    % For double concrete wall selection.
    disp 'Material selected is  "Double Concrete Block Wall".';
    PW_B_CORE = [MOR_6; CON_4; CON_4; MOR_6];
elseif TPW_B_CORE == 3
    % For Timber studs partition wall selection.
    disp 'Material selected is "Timber Studs Wall".';
    PW_B_CORE = [PLAST_4; TIMBER_9; PLAST_4];
elseif TPW_B_CORE == 4
    % For Metal studs partition wall selection.
    disp 'Material selected is "Timber Studs Wall 150x50mm".';
    PW_B_CORE = CLAY_2;
elseif TPW_B_CORE == 5
    % For Metal studs partition wall selection.
    disp 'Material selected is "Light Metal Studs Wall 70x50mm"';
    PW_B_CORE = CLAY_2;
else
    disp 'Type of Partition wall is not properly defined';
    disp 'By default "Double Brick Wall" is selected';
    TPW_B_CORE = 1;
    PW_B_CORE = [MOR_6; CLAY_2; MOR_6];
    disp ' ';
end
```

(3.2.5.1.1) SPEC_PW1_B - Partition wall 1 composition of variables program file

```matlab
if TPW_B ~= 1
    PW_B = [IW_B_finish; PLAST_3; PW_B_INS; PW_B_CORE; PW_B_INS;
PLAST_3; IW_B_finish; subtotal];
else
    PW_B = [IW_B_finish; PLAST_3; PW_B_CORE; PLAST_3; IW_B_finish;
subtotal];
end

% Read the projectSPECbase excel in order to operate with it
specpwbnum = cell2mat(PW_B(1:end-2,3:9));
[pwb,pwb2] = size(specpwbnum);

% Write PARTITION WALL into the ProjectSPECbase excel:

% FOR MAC:
writecell(PW_B(:,1:end-1),ProjectSPECbase,'sheet','PAR_WALLS-
1','range','B4');
writecell(PW_B(:,end),ProjectSPECbase,'sheet','PAR_WALLS-
1','range','AD4');
```

319

(3.2.5.2) BASE_PW2 - Partition wall 2 program file

```
clc;
disp '3.2.5.2. DEFINING THE PARTITION WALL-2';
disp 'If your Partition Wall type is not defined type "0". Thank you. ';
disp ' ';
disp '(1) Not insulated (default option)';
disp '(2) Acoustically Insulated (Acoustic Soundblock Plasterboard)';
disp '(3) Thermally insulated 50mm Expanded Polystyrenne';
disp '(4) Both Thermally & Soundproof Insulated';
disp ' ';
TPW2_B=input('Please define the type of PW-2: ');
disp ' ';
if TPW2_B == 2
    PW2_B_INS = PLAST_3;
elseif TPW2_B == 3
    PW2_B_INS = INS_5D;
elseif TPW2_B == 4
    PW2_B_INS = [INS_5D; PLAST_3];
else
    disp 'You are selecting an Party Wall-2 without Insulation.';
    disp 'This might not be compliant with current Building
Regulations';
    disp ' ';
    disp ' ';
    TPW2_B = 1;
    PW2_B_INS = 'NO_INS'; % This is for the results file name only
end
disp ' ';
```

Select type of structure material:

```
disp '(1) Duoble Brick Wall(d=215mm) (default option)';
disp '(2) Double Light Concrete Blocks (d=200mm)';
disp '(3) Cross Laminated Timber CLT d=116mm with light metal battens';
disp '(4) Timber studs 150x50mm @600mm';
disp '(5) Light metal 70x50mm @600mm';
TPW2_B_CORE=input('Please select the material used for PW-2: ');
disp ' ';
% Then define the core material used for partition walls:
if TPW2_B_CORE == 1
    % For double brick wall selection.
    disp 'Material selected is "Double Brick Wall".';
    PW2_B_CORE = [MOR_6; CLAY_2; MOR_6];

elseif TPW2_B_CORE == 2
    % For double concrete wall selection.
    disp 'Material selected is  "Double Concrete Block Wall".';
    PW2_B_CORE = [MOR_6; CON_4; CON_4; MOR_6];
```

```
elseif TPW2_B_CORE == 3
    % For Timber studs partition wall selection.
    disp 'Material selected is "Timber Studs Wall".';
    PW2_B_CORE = [PLAST_4; TIMBER_9; PLAST_4];
elseif TPW2_B_CORE == 4
    % For Metal studs partition wall selection.
    disp 'Material selected is "Timber Studs Wall 150x50mm".';
    PW2_B_CORE = CLAY_2;
elseif TPW2_B_CORE == 5
    % For Metal studs partition wall selection.
    disp 'Material selected is "Light Metal Studs Wall 70x50mm"';
    PW2_B_CORE = CLAY_2;
else
    disp 'Type of Partition wall is not properly defined';
    disp 'By default "Double Brick Wall" is selected';
    TPW2_B_CORE = 1;
    PW2_B_CORE = [MOR_6; CLAY_2; MOR_6];
    disp ' ';
end
```

(3.2.5.2.1) SPEC_PW2_B - Partition wall 2 composition of variables program file

```
 if TPW2_B ~= 1
     PW2_B = [IW_B_finish; PLAST_3; PW2_B_INS; PW2_B_CORE; PW2_B_INS;
PLAST_3; IW_B_finish; subtotal];
 else
     PW2_B = [IW_B_finish; PLAST_3; PW2_B_CORE; PLAST_3; IW_B_finish;
subtotal];
 end
 % Read the projectSPECbase excel in order to operate with it
 specpw2bnum = cell2mat(PW2_B(1:end-2,3:9));
 [pw2b,pw2b2] = size(specpw2bnum);
 % Write PW2_B into ProjectSPECbase excel:
 writecell(PW2_B(:,1:end-1),ProjectSPECbase,'sheet','PAR_WALLS-
2','range','B4');
 writecell(PW2_B(:,end),ProjectSPECbase,'sheet','PAR_WALLS-
2','range','AD4');
```

(3.2.6.p) BASE_WIN - External Windows program file

```
disp '3.2.6 DEFINING THE WINDOWS OF THE PROJECT: BASELINE';
disp 'If your Window is not defined type "0". Thank you. ';
disp ' ';
disp '(1) Timber framed-single glazed';
disp '(2) Timber framed-double glazed(default option)';
disp '(3) PVC framed-double glazed';
disp '(4) Aluminium framed-double glazed';
disp '(N/A) Triple glazing options are not currently avaiable';
TWIN_B=input('Please define the type of Window: ');
disp ' ';
if TWIN_B == 1
    TWIN_B_CORE = WIN_1;
elseif TWIN_B == 2
    TWIN_B_CORE = WIN_2;
elseif TWIN_B == 3
    TWIN_B_CORE = WIN_3;
elseif TWIN_B == 4
    TWIN_B_CORE = WIN_4;
else
    disp 'Type of Window is not defined properly.';
    disp 'By default "Timber window (double glazed)" is selected';
    TWIN_B_CORE = WIN_2;
end
```

(3.2.7.p) BASE_EXD - External Doors program file

```
disp '3.2.7. DEFINING THE EXTERNAL DOORS OF THE PROJECT-SCENARIO 1:
BASELINE';

% disp ' ';
% disp 'By default "PVC framed External Door" is selected';
% TEXD_B_CORE = EXT_DOOR_2;

disp ' ';
disp 'If your External Door is not defined type "0". Thank you. ';
disp ' ';
disp '(1) Timber framed Door (default option)';
disp '(2) PVC framed Door';
TEXD_B=input('Please define the type of Door: ');
disp ' ';
if TEXD_B == 1
    TEXD_B_CORE = EXT_DOOR_1;
elseif TEXD_B == 2
    TEXD_B_CORE = EXT_DOOR_2;
else
    disp 'Type of external door is not defined properly.';
```

```
    disp 'By default "Timber framed door" is selected';
    TEXD_B_CORE = EXT_DOOR_1;
end
```

(3.2.8.p) BASE_IND - Internal Door program file

```
disp '3.2.8. DEFINING THE INTERNAL DOORS OF THE PROJECT: BASELINE';

% If there are no internal door selection options
disp ' ';
disp 'By default "Timber framed Internal Door" is selected';
TIND_B_CORE = INT_DOOR_1;
```

(3.3.p) Internal finishes definition

(3.3.1) BASE_IW_FINISH program file

```
% TYPE OF INTERNAL WALL FINISH: BASELINE
disp '3.3. Definingn INTERNAL FINISHES of the project: BASELINE';
disp ' ';
disp '3.3.1. Definingn Internal Wall finish';
disp ' ';
disp '(1) General paint-2 coats (default option)';
disp '(2) Wallpaper';
disp '(3) Ceramic Wall tile';
disp '(4) No finish';
disp ' ';
TIW_B_finish=input('Please select the Internal Wall finish: ');

if TIW_B_finish == 1
    disp ' ';
    disp 'The internal wall finish selected is General Paint (2 coats)';
    IW_B_finish = FIN_2;

elseif TIW_B_finish == 2
    disp ' ';
    disp 'The internal wall finish selected is Wallpaper';
    IW_B_finish = FIN_6;

elseif TIW_B_finish == 3
    disp ' ';
    disp 'The internal wall finish selected is Ceramic Wall Tiles';
    IW_B_finish = [MOR_1; CLAY_4];
elseif TIW_B_finish == 4
    disp ' ';
    disp 'The internal wall finish selected is "No Finish"';
    IW_B_finish = OTHER_6;
else
    disp ' ';
    disp 'Internal wall finish is not properly define. ';
    disp 'By default Internal wall finish selected is General Paint (2
coats)';
    IW_B_finish =  FIN_2;
end
disp ' ';
```

(3.3.2) BASE_FLOOR_FINISH program file

```
% TYPE OF FLOOR FINISH: BASELINE
disp '3.3.2. Defining Floor finish:';
disp ' ';
disp '(1) General carpet (default option)';
disp '(2) Laminate floor';
```

```matlab
 disp '(3) Ceramic floor tiles';
 disp '(4) Vinyl flooring';
 T_Floor_B_finish=input('Please select the floor Finish: ');

 if T_Floor_B_finish == 1
     disp ' ';
     disp ' ';
     disp 'Floor Finish selected is General Carpet over chipboards d=22mm
and softwood battens 50x50mm @600mm';
     BASE_Floor_finish = [FIN_5; TIMBER_1; TIMBER_11];

 elseif T_Floor_B_finish == 2
     disp ' ';
     disp ' ';
     disp 'Floor Finish selected is Laminated Floor';
     BASE_Floor_finish = [MOR_2; OTHER_1; FIN_6];

 elseif T_Floor_B_finish == 3
     disp ' ';
     disp ' ';
     disp 'Floor Finish selected is Ceramic Floor tiles';
     BASE_Floor_finish = [OTHER_3; MOR_2; CLAY_4];
 elseif T_Floor_B_finish == 4
     disp ' ';
     disp ' ';
     disp 'Floor Finish selected is Vinyl Flooring';
     BASE_Floor_finish = [FIN_7; MOR_1];
 else
     disp ' ';
     disp 'Type of Floor Finish is not properly defined';
     disp 'By default "General carpet" is selected';
     BASE_Floor_finish = FIN_5;
 end
 disp ' ';
 disp ' ';
```

(3.3.3) BASE_CEILING_FINISH program file

```matlab
 % TYPE OF CEILING FINISH: BASELINE
 disp '3.3.3. Definingn Ceiling finish';
 disp ' ';
 disp 'By default "Plasterboard and general paint (2 coats)" is
selected';
 CF_B_finish = [PLAST_5; PLAST_3; FIN_2];

 disp ' ';
 disp ' ';
```

(4) Tool calculation algorithms

```
formatOut = 'yyyy_mm_dd';
DATE=datestr(date,formatOut);
% NORMAL WAY
FILE_ENV_NAME = strcat(P_NAME,'_',SCENARIO,'_ENV_',DATE,'.mat');

% FOR CGALAN VALIDATION:
% FILE_ENV_NAME = strcat(P_NAME,'_ENV_',DATE,'.mat');
```

Calculating Transport Loads for Module "A4:Gate to Site" + "C2: Site to Landfilling Site".
(4.1) Transport calculation program to get the impact per kg of material.

```
run LCA_Transport;
```

(4.2) Calculating operational stage impacts from energy demand:

```
run LCA_use_phase;
```

(4.3) Environmental calculations

```
run LCA_calculations2_2004Mac
```

PREPARING THE EXCEL FILE FOR EVIRONMENTAL DATA SUMMARY.

```
projectENVdata = strcat('4_ProjectENV_',P_NAME,'_',SCENARIO,'_',
DATE,'.xlsx'); % NORMAL WAY
% projectENVdata = strcat('4_ProjectENV_',P_NAME,'_',DATE,'.xlsx'); % FOR
CGALAN VALIDATION

specsumheaders_s = {'Element','Area','INDICATORS','','','';
                    'Name','(m2)','KgCO2e/m2','MJ/m2','KgCO2e','MJ'};
specsumheaders_e = {'Element','Area','','MANUFACTURING','USE-
REPLACEMENT','END-OF-LIFE','';
                    'Name','(m2)','Indicator','A','B','C','SubTotal'};
specsumheaders_ee =
{'Element','Area','','MANUFACTURING','','','','','','USE-
REPLACEMENT','','','','','END-OF-LIFE','','','','';
                    'Name','(m2)','Indicator','A1-A3','A4','A5-a','A5-
b','A5-c','A5-d','A5-
e','B4_a','B4_b','B4_c','B4_d','B6','C1','C2','C3','C4','SubTotal'};

% For windows
% xlswrite(projectENVdata,specsumheaders_s,'SUMMARY_S');
% xlswrite(projectENVdata,specsumheaders_e,'SUMMARY_E');
% xlswrite(projectENVdata,specsumheaders_ee,'SUMMARY_EE');

% For Mac:
writecell(specsumheaders_s,projectENVdata,'sheet','SUMMARY_S');
writecell(specsumheaders_e,projectENVdata,'sheet','SUMMARY_E');
```

```
writecell(specsumheaders_ee,projectENVdata,'sheet','SUMMARY_EE');
```

Creating Summary file

There will be short and extended summaries versions This will consist in the subtotals by m2 transformed into global figures

```
SUMMARY_S_1={'Foundations',B_FP_A;
             'Ground Floor',B_FP_A;
             'Upper Floor',B_FP_A;
             'Roof',B_ROOF_A;};


SUMMARY_S_3={'Windows',B_WIN_A;
             'External Doors',B_EDO_A;
             'Internal Doors',B_IDO_A;
             '','TOTALS'};

SUMMARY_E_1={'Foundations',B_FP_A,'KgCO2e';
             '','','MJ';
             'Ground Floor',B_FP_A,'KgCO2e';
             '','','MJ';
             'Upper Floor',B_FP_A,'KgCO2e';
             '','','MJ';
             'Roof',B_ROOF_A,'KgCO2e';
             '','','MJ'};

SUMMARY_E_3={'Windows',B_WIN_A,'KgCO2e';
             '','','MJ';
             'External Doors',B_EDO_A,'KgCO2e';
             '','','MJ';
             'Internal Doors',B_IDO_A,'KgCO2e';
             '','','MJ';
             'TOTALS','','KgCO2e';
             '','','MJ'};

if B_T == 5
    if T_EW == 2

        SUMMARY_S_2={'External Wall - 1',B_EW_A;
             'External Wall - 2',B_EW2_A;
             'Internal Walls',B_IW_A;
             'Party Wall - 1',B_PW1_A;
             'Party Wall - 2',B_PW2_A};

        SUMMARY_E_2={'External Wall - 1',B_EW_A,'KgCO2e';
             '','','MJ';
             'External Wall - 2',B_EW2_A,'KgCO2e';
             '','','MJ';
             'Internal Walls',B_IW_A,'KgCO2e';
             '','','MJ';
             'Partition Wall - 1',B_PW1_A,'KgCO2e';
```

328

```matlab
            '','','MJ'
            'Partition Walls - 2',B_PW2_A,'KgCO2e';
            '','','MJ'};
        % Create array of zeros in order to avoid problems with totals
        X = zeros(13,4);
        Y = zeros(26,4);
        Z = zeros(26,17);

    elseif T_EW == 3

        SUMMARY_S_2={'External Wall - 1',B_EW_A;
            'External Wall - 2',B_EW2_A;
            'External Wall - 3',B_EW3_A;
            'Party Wall - 1',B_PW1_A;
            'Party Wall - 2',B_PW2_A;
            'Internal Walls',B_IW_A};

        SUMMARY_E_2={'External Wall - 1',B_EW_A,'KgCO2e';
            '','','MJ';
            'External Wall - 2',B_EW2_A,'KgCO2e';
            '','','MJ';
            'External Wall - 3',B_EW3_A,'KgCO2e';
            '','','MJ';
            'Partition Wall - 1',B_PW1_A,'KgCO2e';
            '','','MJ'
            'Partition Walls - 2',B_PW2_A,'KgCO2e';
            '','','MJ';
            'Internal Walls',B_IW_A,'KgCO2e';
            '','','MJ'};
        % Create array of zeros in order to avoid problems with totals
        X = zeros(14,4);
        Y = zeros(28,4);
        Z = zeros(28,17);
    end

else
    SUMMARY_S_2={'External Walls',B_EW_A;
            'Party Walls',B_PW1_A;
            'Internal Walls',B_IW_A};

    SUMMARY_E_2={'External Wall',B_EW_A,'KgCO2e';
            '','','MJ';
            'Partition Wall',B_PW1_A,'KgCO2e';
            '','','MJ';
            'Internal Walls',B_IW_A,'KgCO2e';
            '','','MJ'};

    % Create array of zeros in order to avoid problems with totals
    X = zeros(11,4);
    Y = zeros(22,4);
```

```
    Z = zeros(22,17);
end
```

Create one only matrix with all titles

```
SUMMARY_S = [SUMMARY_S_1;SUMMARY_S_2;SUMMARY_S_3];
SUMMARY_E = [SUMMARY_E_1;SUMMARY_E_2;SUMMARY_E_3];
% get size of matrix used for totals depending the project assessed
[sumsb,sumsb2] = size(SUMMARY_S);
[sumeb,sumeb2] = size(SUMMARY_E);
```

transfer to spreadsheet file:

for windows:
xlswrite(projectENVdata,[SUMMARY_S_1;SUMMARY_S_2;SUMMARY_S_3],'SUMMARY
_S','A3');
xlswrite(projectENVdata,[SUMMARY_E_1;SUMMARY_E_2;SUMMARY_E_3],'SUMMARY
_E','A3');
xlswrite(projectENVdata,[SUMMARY_E_1;SUMMARY_E_2;SUMMARY_E_3],'SUMMARY
_EE','A3');

```
%for mac:
writecell(SUMMARY_S,projectENVdata,'sheet','SUMMARY_S','range','A3');
writecell(SUMMARY_E,projectENVdata,'sheet','SUMMARY_E','range','A3');
writecell(SUMMARY_E,projectENVdata,'sheet','SUMMARY_EE','range','A3');
```

Get the array of zeros to excel spreadsheet

for windows: xlswrite(projectENVdata,X,'SUMMARY_S','C3');
xlswrite(projectENVdata,Y,'SUMMARY_E','D3');
xlswrite(projectENVdata,Z,'SUMMARY_EE','D3');

```
% for mac:
writematrix(X,projectENVdata,'sheet','SUMMARY_S','range','C3');
writematrix(Y,projectENVdata,'sheet','SUMMARY_E','range','D3');
writematrix(Z,projectENVdata,'sheet','SUMMARY_EE','range','D3');
```

EXTENDED Summary version

This will consist in the subtotals by m2 by LCA stage transformed into global figures by Stages.

```
for j=26
```

Foundations Subtotals and Totals:

Short version (TOTAL)

```
B_FO_s = specfobnum(fob+1:fob+2,j);
B_FO_s_SubT = B_FO_s*B_FP_A;
```

Extended version (A,B,C,TOTAL)

```
B_FO_e = specfobnum(fob+1:fob+2,j-3:j);
B_FO_e_SubT = B_FO_e*B_FP_A;
```

Extra Extended version (A1-A3,A4,A5,B4,B6,C1,C2,C3,C4,TOTAL)

```
B_FO_ee = [specfobnum(fob+1:fob+2,7:j-4),specfobnum(fob+1:fob+2,j)];
B_FO_ee_SubT = B_FO_ee*B_FP_A;
% end
```

External Wall Subtotals

for j=26 Short version (TOTAL)

```
B_EW_s = specewbnum(ewb+1:ewb+2,j);
B_EW_s_subT = B_EW_s*B_EW_A;

% Extended version (A,B,C,TOTAL)
B_EW_e = specewbnum(ewb+1:ewb+2,j-3:j);
B_EW_e_SubT = B_EW_e*B_EW_A;

% Extra Extended version (A1-A3,A4,A5,B4,B6,C1,C2,C3,C4,TOTAL)
B_EW_ee = [specewbnum(ewb+1:ewb+2,7:j-4),specewbnum(ewb+1:ewb+2,j)];
B_EW_ee_subT = B_EW_ee*B_EW_A;
% end
if T_EW ~= 1
    % Short version (TOTAL)
    B_EW2_s = specew2bnum(ew2b+1:ew2b+2,j);
    B_EW2_s_subT = B_EW2_s*B_EW2_A;

    % Extended version (A,B,C,TOTAL)
    B_EW2_e = specew2bnum(ew2b+1:ew2b+2,j-3:j);
    B_EW2_e_SubT = B_EW2_e*B_EW2_A;

    % Extra Extended version (A1-A3,A4,A5,B4,B6,C1,C2,C3,C4,TOTAL)
    B_EW2_ee = [specew2bnum(ew2b+1:ew2b+2,7:j-
4),specew2bnum(ew2b+1:ew2b+2,j)];
    B_EW2_ee_subT = B_EW2_ee*B_EW2_A;
    % end
    if T_EW == 3
        B_EW3_s = specew3bnum(ew3b+1:ew3b+2,j);
        B_EW3_s_subT = B_EW3_s*B_EW3_A;

        % Extended version (A,B,C,TOTAL)
        B_EW3_e = specew3bnum(ew3b+1:ew3b+2,j-3:j);
        B_EW3_e_SubT = B_EW3_e*B_EW3_A;

        % Extra Extended version (A1-A3,A4,A5,B4,B6,C1,C2,C3,C4,TOTAL)
        B_EW3_ee = [specew3bnum(ew3b+1:ew3b+2,7:j-
4),specew3bnum(ew3b+1:ew3b+2,j)];
        B_EW3_ee_subT = B_EW3_ee*B_EW3_A;
        % end
    end

end
```

331

Internal Wall Subtotals

for j=26 Short version (TOTAL)

```
B_IW_s = speciwbnum(iwb+1:iwb+2,j);
B_IW_s_subT = B_IW_s*B_IW_A;

% Extended version (A,B,C,TOTAL)
B_IW_e = speciwbnum(iwb+1:iwb+2,j-3:j);
B_IW_e_subT = B_IW_e*B_IW_A;

% Extra Extended version (A1-A3,A4,A5,B4,B6,C1,C2,C3,C4,TOTAL)
B_IW_ee = [speciwbnum(iwb+1:iwb+2,7:j-4),speciwbnum(iwb+1:iwb+2,j)];
B_IW_ee_subT = B_IW_ee*B_IW_A;
% end
```

Partition Wall Subtotals

for j=26 Short version (TOTAL)

```
if B_T ~= 4
B_PW_s = specpwbnum(pwb+1:pwb+2,j);
B_PW_s_subT = B_PW_s*B_PW1_A;

% Extended version (A,B,C,TOTAL)
B_PW_e = specpwbnum(pwb+1:pwb+2,j-3:j);
B_PW_e_subT = B_PW_e*B_PW1_A;

% Extra Extended version (A1-A3,A4,A5,B4,B6,C1,C2,C3,C4,TOTAL)
B_PW_ee = [specpwbnum(pwb+1:pwb+2,7:j-4),specpwbnum(pwb+1:pwb+2,j)];
B_PW_ee_subT = B_PW_ee*B_PW1_A;
% end

if B_T == 5
    % Short version (TOTAL)
    B_PW2_s = specpw2bnum(pw2b+1:pw2b+2,j);
    B_PW2_s_subT = B_PW2_s*B_PW2_A;

    % Extended version (A,B,C,TOTAL)
    B_PW2_e = specpw2bnum(pw2b+1:pw2b+2,j-3:j);
    B_PW2_e_subT = B_PW2_e*B_PW2_A;

    % Extra Extended version (A1-A3,A4,A5,B4,B6,C1,C2,C3,C4,TOTAL)
    B_PW2_ee = [specpw2bnum(pw2b+1:pw2b+2,7:j-
4),specpw2bnum(pw2b+1:pw2b+2,j)];
    B_PW2_ee_subT = B_PW2_ee*B_PW2_A;
end
end
```

Subtotals for Ground Floors

for j=26 Short version (TOTAL)

```matlab
B_GF_s = specgfbnum(gfb+1:gfb+2,j);
B_GF_s_subT = B_GF_s*B_FP_A;

% Extended version (A,B,C,TOTAL)
B_GF_e = specgfbnum(gfb+1:gfb+2,j-3:j);
B_GF_e_SubT = B_GF_e*B_FP_A;

% Extra Extended version (A1-A3,A4,A5,B4,B6,C1,C2,C3,C4,TOTAL)
B_GF_ee = [specgfbnum(gfb+1:gfb+2,7:j-4),specgfbnum(gfb+1:gfb+2,j)];
B_GF_ee_SubT = B_GF_ee*B_FP_A;
% end
```

Subtotals for Upper Floors

for j=26 Short version (TOTAL)

```matlab
B_UF_s = specufbnum(ufb+1:ufb+2,j);
B_UF_s_subT = B_UF_s*B_FP_A;

% Extended version (A,B,C,TOTAL)
B_UF_e = specufbnum(ufb+1:ufb+2,j-3:j);
B_UF_e_subT = B_UF_e*B_FP_A;
% if
% B_UF_e_subT = B_UF_e*B_FP_A*(B_L_N-1);
% else
%     B_UF_e_subT = B_UF_e*B_FP_A;
% end
% Extra Extended version (A1-A3,A4,A5,B4,B6,C1,C2,C3,C4,TOTAL)
B_UF_ee = [specufbnum(ufb+1:ufb+2,7:j-4),specufbnum(ufb+1:ufb+2,j)];
B_UF_ee_subT = B_UF_ee*B_FP_A;
% end
```

Subtotals for Roofs

for j=26 Short version (TOTAL)

```matlab
B_R_s = specroofbnum(rb+1:rb+2,j);
B_R_s_SubT = B_R_s*B_FP_A;

% Extended version (A,B,C,TOTAL)
B_R_e = specroofbnum(rb+1:rb+2,j-3:j);
B_R_e_SubT = B_R_e*B_FP_A;

% Extra extended version (A1-A3,A4,A5,B4,B6,C1,C2,C3,C4,TOTAL)
B_R_ee = [specroofbnum(rb+1:rb+2,7:j-4),specroofbnum(rb+1:rb+2,j)];
B_R_ee_SubT = B_R_ee*B_FP_A;

% end
```

Subtotals for External Doors

for j=26 Short version (TOTAL)

```
B_ED_s = specindbnum(edob+1:edob+2,j);
B_ED_s_subT = B_ED_s*B_EDO_A;

% Extended version (A,B,C,TOTAL)
B_ED_e = specexdbnum(edob+1:edob+2,j-3:j);
B_ED_e_subT = B_ED_e*B_EDO_A;

% Extra Extended version (A1-A3,A4,A5,B4,B6,C1,C2,C3,C4,TOTAL)
B_ED_ee = [specexdbnum(edob+1:edob+2,7:j-
4),specexdbnum(edob+1:edob+2,j)];
B_ED_ee_subT = B_ED_ee*B_EDO_A;
% end
```

Subtotals for Internal Doors

for j=26 Short version (TOTAL)

```
B_ID_s = specindbnum(idob+1:idob+2,j);
B_ID_s_subT = B_ID_s*B_IDO_A;

% Extended version (A,B,C,TOTAL)
B_ID_e = specindbnum(idob+1:idob+2,j-3:j);
B_ID_e_subT = B_ID_e*B_IDO_A;

% Extra Extended version (A1-A3,A4,A5,B4,B6,C1,C2,C3,C4,TOTAL)
B_ID_ee = [specindbnum(idob+1:idob+2,7:j-
4),specindbnum(idob+1:idob+2,j)];
B_ID_ee_subT = B_ID_ee*B_IDO_A;
% end
```

Subtotals for Windows

for j=26 Short version (TOTAL)

```
B_W_s = specwinbnum(wb+1:wb+2,j);
B_W_s_subT = B_W_s*B_WIN_A;

% Extended version (A,B,C,TOTAL)
B_W_e = specwinbnum(wb+1:wb+2,j-3:j);
B_W_e_subT = B_W_e*B_WIN_A;

% Extended version (A1-A3,A4,A5,B4,B6,C1,C2,C3,C4,TOTAL)
B_W_ee = [specwinbnum(wb+1:wb+2,7:j-4),specwinbnum(wb+1:wb+2,j)];
B_W_ee_subT = B_W_ee*B_WIN_A;
% end

end
```

CREATING THE TOTALS FOR THE BUILDING

SHORT VERSION (TOTALS BY BUILDING ELEMENT)

334

Baseline Building Impact loads by Building Element.

By indicator/m2:

```
BASELINE_S_1=[B_FO_s';B_GF_s'; B_UF_s'; B_R_s';];
if B_T ~= 4
    if B_T == 5 % if there are more than 1 EW and PW:
        if T_EW ~= 1
            BASELINE_S_2=[B_EW_s'; B_EW2_s'; B_PW_s'; B_PW2_s'];
            if T_EW == 3
                BASELINE_S_2=[B_EW_s'; B_EW2_s'; B_EW3_s';B_PW_s';
B_PW2_s'];
            end
        end
    else
    BASELINE_S_2=[B_EW_s'; B_PW_s'];
    end
else
    BASELINE_S_2=B_EW_s';
end
BASELINE_S_3=[B_IW_s'; B_W_s'; B_ED_s'; B_ID_s'];
BASELINE_S=[BASELINE_S_1;BASELINE_S_2;BASELINE_S_3];

BASELINE_S_TOTAL_1=B_FO_s'+B_GF_s'+B_UF_s';
if B_T ~= 4
    if B_T == 5 % if there are more than 1 EW and PW:
        if T_EW ~= 1
            BASELINE_S_TOTAL_2=B_EW_s'+B_EW2_s'+B_PW_s'+B_PW2_s';
            if T_EW == 3

BASELINE_S_TOTAL_2=B_EW_s'+B_EW2_s'+B_EW3_s'+B_PW_s'+B_PW2_s';
            end
        end
    else
    BASELINE_S_TOTAL_2=B_EW_s'+B_PW_s';
    end
else
    BASELINE_S_TOTAL_2=B_EW_s';
end
BASELINE_S_TOTAL_3=B_IW_s'+B_R_s'+B_W_s'+B_ED_s'+B_ID_s';
BASELINE_S_TOTAL=BASELINE_S_TOTAL_1+BASELINE_S_TOTAL_2+BASELINE_S_TOTAL_3
;


% Getting TOTAL loads by Indicator/m2:
BASELINE_S_EC = BASELINE_S(:,1);
BASELINE_S_EE = BASELINE_S(:,2);
BASELINE_S_TOTAL_EC = BASELINE_S_TOTAL(:,1);
BASELINE_S_TOTAL_EE = BASELINE_S_TOTAL(:,2);
```

Building element multiplied by square meter ("SubT" files):

```
BASELINE_S_SUBT_1=[B_FO_s_SubT';B_GF_s_subT';B_UF_s_subT';B_R_s_SubT'];
if B_T ~= 4
    if B_T == 5 % if there are more than 1 EW and PW:
        if T_EW ~= 1

BASELINE_S_SUBT_2=[B_EW_s_subT';B_EW2_s_subT';B_PW_s_subT';B_PW2_s_subT']
;
            if T_EW == 3

BASELINE_S_SUBT_2=[B_EW_s_subT';B_EW2_s_subT';B_EW3_s_subT';B_PW_s_subT';
B_PW2_s_subT'];
            end
        end
    else
        BASELINE_S_SUBT_2=[B_EW_s_subT';B_PW_s_subT'];
    end
else
    BASELINE_S_SUBT_2=B_EW_s_subT';
end

BASELINE_S_SUBT_3=[B_IW_s_subT';B_W_s_subT';B_ED_s_subT';B_ID_s_subT'];
BASELINE_S_SUBT=[BASELINE_S_SUBT_1;BASELINE_S_SUBT_2;BASELINE_S_SUBT_3];
```

getting totals:

```
BASELINE_S_SUBT_TOTAL_1=B_FO_s_SubT'+B_GF_s_subT'+B_UF_s_subT';
if B_T ~= 4
    if B_T == 5 % if there are more than 1 EW and PW:
        if T_EW ~= 1

BASELINE_S_SUBT_TOTAL_2=B_EW_s_subT'+B_EW2_s_subT'+B_PW_s_subT'+B_PW2_s_s
ubT';
            if T_EW == 3

BASELINE_S_SUBT_TOTAL_2=B_EW_s_subT'+B_EW2_s_subT'+B_EW3_s_subT'+B_PW_s_s
ubT'+B_PW2_s_subT';
            end
        end
    else
        BASELINE_S_SUBT_TOTAL_2=B_EW_s_subT'+B_PW_s_subT';
    end
else
    BASELINE_S_SUBT_TOTAL_2=B_EW_s_subT';
end
BASELINE_S_SUBT_TOTAL_3=B_IW_s_subT'+B_R_s_SubT'+B_W_s_subT'+B_ED_s_subT'
+B_ID_s_subT';

BASELINE_S_SUBT_TOTAL=BASELINE_S_SUBT_TOTAL_1+BASELINE_S_SUBT_TOTAL_2+BAS
ELINE_S_SUBT_TOTAL_3;
```

```
% Getting loads by Indicator
BASELINE_S_SUBT_EC = BASELINE_S_SUBT(:,1);
BASELINE_S_SUBT_EE = BASELINE_S_SUBT(:,2);
BASELINE_S_SUBT_TOTAL_EC = BASELINE_S_SUBT_TOTAL(:,1);
BASELINE_S_SUBT_TOTAL_EE = BASELINE_S_SUBT_TOTAL(:,2);
```

Writing in excel the totals of the building SHORT version.

Baseline

```
% FOR WINDOWS:
%
xlswrite(projectENVdata,[BASELINE_S;BASELINE_S_TOTAL],'SUMMARY_S','C3');
% % xlswrite(projectENVdata,BASELINE_S,'SUMMARY_S','C3');
% % xlswrite(projectENVdata,BASELINE_S_TOTAL,'SUMMARY_S','C16');
%
xlswrite(projectENVdata,[BASELINE_S_SUBT;BASELINE_S_SUBT_TOTAL],'SUMMARY_
S','E3');
% % xlswrite(projectENVdata,BASELINE_S_SUBT,'SUMMARY_S','E3');
% % xlswrite(projectENVdata,BASELINE_S_SUBT_TOTAL,'SUMMARY_S','E16');

% FOR MAC:
writematrix([BASELINE_S;
BASELINE_S_TOTAL],projectENVdata,'sheet','SUMMARY_S','range','C3');
%
writematrix(BASELINE_S,projectENVdata,'sheet','SUMMARY_S','range','C3');
%
writematrix(BASELINE_S_TOTAL,projectENVdata,'sheet','SUMMARY_S','range','
C16');
writematrix([BASELINE_S_SUBT;BASELINE_S_SUBT_TOTAL],projectENVdata,'sheet
','SUMMARY_S','range','E3');
%
writematrix(BASELINE_S_SUBT,projectENVdata,'sheet','SUMMARY_E','range','E
3');
%
writematrix(BASELINE_S_SUBT_TOTAL,projectENVdata,'sheet','SUMMARY_E','ran
ge','E16');
```

RESULT FOR VALIDATION WITH C_GALAN PAPER:

RESULT_CGALAN = [BASELINE_S(5,:);BASELINE_S_SUBT(5,:)]

EXTENDED VERSION (A,B,C,TOTAL)

```
% Building element already multiplied by square metre (excluding energy
demand and construction and demolition works):
BASELINE_E_SUBT_NO_B6_1 =
[B_FO_e_SubT;B_GF_e_SubT;B_UF_e_subT;B_R_e_SubT];
if B_T ~= 4
    if B_T == 5 % if there are more than 1 EW and PW:
        if T_EW ~= 1
```

```
            BASELINE_E_SUBT_NO_B6_2 =
[B_EW_e_SubT;B_EW2_e_SubT;B_PW_e_subT;B_PW2_e_subT];
            if T_EW == 3
                BASELINE_E_SUBT_NO_B6_2 =
[B_EW_e_SubT;B_EW2_e_SubT;B_EW3_e_SubT;B_PW_e_subT;B_PW2_e_subT];
            end
        end
    else
        BASELINE_E_SUBT_NO_B6_2 = [B_EW_e_SubT;B_PW_e_subT];
    end
else
    BASELINE_E_SUBT_NO_B6_2 = B_EW_e_SubT;
end
BASELINE_E_SUBT_NO_B6_3 =
[B_IW_e_subT;B_W_e_subT;B_ED_e_subT;B_ID_e_subT];
BASELINE_E_SUBT_NO_B6=[BASELINE_E_SUBT_NO_B6_1;BASELINE_E_SUBT_NO_B6_2;BA
SELINE_E_SUBT_NO_B6_3];

BASELINE_E_SUBT_EC_NO_B6 = BASELINE_E_SUBT_NO_B6(1:2:end,:);
BASELINE_E_SUBT_EE_NO_B6 = BASELINE_E_SUBT_NO_B6(2:2:end,:);
% Getting Total loads by Indicator:
BASELINE_E_SUBT_TOTAL_EC_NO_B6=sum(BASELINE_E_SUBT_NO_B6(1:2:end,:));
BASELINE_E_SUBT_TOTAL_EE_NO_B6=sum(BASELINE_E_SUBT_NO_B6(2:2:end,:));
BASELINE_E_SUBT_TOTAL_NO_B6 =
[BASELINE_E_SUBT_TOTAL_EC_NO_B6;BASELINE_E_SUBT_TOTAL_EE_NO_B6];

%for windows:
%
xlswrite(projectENVdata,[BASELINE_E_SUBT;BASELINE_E_SUBT_TOTAL],'SUMMARY_
E','D3');
% xlswrite(projectENVdata,BASELINE_E_SUBT,'SUMMARY_E','D3');
% xlswrite(projectENVdata,BASELINE_E_SUBT_TOTAL,'SUMMARY_E','D30');

% for mac:
writematrix([BASELINE_E_SUBT_NO_B6;BASELINE_E_SUBT_TOTAL_NO_B6],projectEN
Vdata,'sheet','SUMMARY_E','range','D3');
%
writematrix(BASELINE_E_SUBT,projectENVdata,'sheet','SUMMARY_E','range','D
3');
%
writematrix(BASELINE_E_SUBT_TOTAL,projectENVdata,'sheet','SUMMARY_E','ran
ge','D30');

% What is this?
% sum(specfobnum(1:2:fob,j)
```

EXTRA EXTENDED VERSION (A1-A3,A4,A5,B4,B6,C1,C2,C3,C4,TOTAL)

By squre metre: BASELINE_EE = B_FO_ee + B_GF_ee + B_UF_ee + B_EW_ee +
B_IW_ee + B_PW_ee + B_R_ee + B_D_ee + B_W_ee; BASELINE_EE_TOTAL =
[B_FO_ee;B_GF_ee;B_UF_ee;B_EW_ee;B_IW_ee;B_PW_ee;B_R_ee;B_D_ee;B_W_ee];

```matlab
% By Building element multiplied by square metre:
BASELINE_EE_SUBT_1 =
[B_FO_ee_SubT;B_GF_ee_SubT;B_UF_ee_subT;B_R_ee_SubT];
if B_T ~= 4
    if B_T == 5 % if there are more than 1 EW and PW:
        if T_EW ~= 1
            BASELINE_EE_SUBT_2 =
[B_EW_ee_subT;B_EW2_ee_subT;B_PW_ee_subT;B_PW2_ee_subT];
            if T_EW == 3
                BASELINE_EE_SUBT_2 =
[B_EW_ee_subT;B_EW2_ee_subT;B_EW3_ee_subT;B_PW_ee_subT;B_PW2_ee_subT];
            end
        end
    else
        BASELINE_EE_SUBT_2 = [B_EW_ee_subT;B_PW_ee_subT];
    end
else
    BASELINE_EE_SUBT_2 = B_EW_ee_subT;
end
BASELINE_EE_SUBT_3 =
[B_IW_ee_subT;B_W_ee_subT;B_ED_ee_subT;B_ID_ee_subT];
BASELINE_EE_SUBT =
[BASELINE_EE_SUBT_1;BASELINE_EE_SUBT_2;BASELINE_EE_SUBT_3];
% BASELINE_EE_SUBT_TOTAL = B_FO_ee_SubT + B_GF_ee_SubT + B_UF_ee_subT +
B_EW_ee_subT + B_IW_ee_subT + B_PW_ee_subT + B_R_ee_SubT + B_D_ee_subT +
B_W_ee_subT;
BASELINE_EE_SUBT_EC = BASELINE_EE_SUBT(1:2:end,:);
BASELINE_EE_SUBT_EE = BASELINE_EE_SUBT(2:2:end,:);
```

Getting Total loads by Indicator with all stages subdivided:

EMBODIED CARBON:

```matlab
BASELINE_EE_SUBT_TOTAL_EC_SI_B6 = sum(BASELINE_EE_SUBT(1:2:end,:));
% ADDING A5, B6 & C1 to building impacts:
BASELINE_EE_SUBT_TOTAL_EC_SI_B6 (1,12) = B6_EMISSION_KGCO2e;
BASELINE_EE_SUBT_TOTAL_EC_SI_B6 (1,7) = B_CONS_REF_EC;
BASELINE_EE_SUBT_TOTAL_EC_SI_B6 (1,13) = BASE_DEM_EC;

% EMBODIED ENERGY:
BASELINE_EE_SUBT_TOTAL_EE_SI_B6=sum(BASELINE_EE_SUBT(2:2:end,:));
% ADDING A5, B6 & C1 to building impacts impacts:
BASELINE_EE_SUBT_TOTAL_EE_SI_B6 (1,7) = B_CONS_REF_EE;
BASELINE_EE_SUBT_TOTAL_EE_SI_B6 (1,12) = B6_ENERGY_MJ;
BASELINE_EE_SUBT_TOTAL_EE_SI_B6 (1,13) = BASE_DEM_EE;

% RESULTS OF THE COMPLETE BUILDING EE AND EC:
BASELINE_EE_SUBT_TOTAL =
[BASELINE_EE_SUBT_TOTAL_EC_SI_B6;BASELINE_EE_SUBT_TOTAL_EE_SI_B6];
```

Writing in excel the totals of the building EXTENDED version.

for windows
xlswrite(projectENVdata,[BASELINE_EE_SUBT;BASELINE_EE_SUBT_TOTAL],'SUMMAR
Y_EE','D3');
writematrix(BASELINE_EE_SUBT,projectENVdata,'sheet','SUMMARY_EE','range','D3');
writematrix(BASELINE_EE_SUBT_TOTAL,projectENVdata,'sheet','SUMMARY_EE','range',
'D30'); for mac

```
writematrix([BASELINE_EE_SUBT;BASELINE_EE_SUBT_TOTAL],projectENVdata,'she
et','SUMMARY_EE','range','D3');
%
writematrix(BASELINE_EE_SUBT,projectENVdata,'sheet','SUMMARY_EE','range',
'D3');
%
writematrix(BASELINE_EE_SUBT_TOTAL,projectENVdata,'sheet','SUMMARY_EE','r
ange','D30');
```

PREPARING TABLES FOR RESULTS:

EXTENDED VERSION

```
%results with B6:
BASELINE_E_SUBT_TOTAL_EC_SI_B6=[BASELINE_E_SUBT_TOTAL_EC_NO_B6(1,1),BASEL
INE_E_SUBT_TOTAL_EC_NO_B6(1,2)+B6_EMISSION_KGCO2e,BASELINE_E_SUBT_TOTAL_E
C_NO_B6(1,3),BASELINE_E_SUBT_TOTAL_EC_NO_B6(1,4)+B6_EMISSION_KGCO2e];
BASELINE_E_SUBT_TOTAL_EE_SI_B6=[BASELINE_E_SUBT_TOTAL_EE_NO_B6(1,1),BASEL
INE_E_SUBT_TOTAL_EE_NO_B6(1,2)+B6_ENERGY_MJ,BASELINE_E_SUBT_TOTAL_EE_NO_B
6(1,3),BASELINE_E_SUBT_TOTAL_EE_NO_B6(1,4)+B6_ENERGY_MJ];
```

EXTRA-EXTENDED VERSION WITH ALL SUBSTAGES DIVIDED:

results without B6:

```
BASELINE_EE_SUBT_TOTAL_EE_NO_B6=[BASELINE_EE_SUBT_TOTAL_EE_SI_B6(:,1:11),
BASELINE_EE_SUBT_TOTAL_EE_SI_B6(:,13:end)];
BASELINE_EE_SUBT_TOTAL_EC_NO_B6=[BASELINE_EE_SUBT_TOTAL_EC_SI_B6(:,1:11),
BASELINE_EE_SUBT_TOTAL_EC_SI_B6(:,13:end)];
```

Grouping results in order to get result by subtages:

```
BASELINE_EE_TOTAL_EE_SI_B6_substages =
[BASELINE_EE_SUBT_TOTAL_EE_SI_B6(:,1:2),sum(BASELINE_EE_SUBT_TOTAL_EE_SI_
B6(:,3:7)),sum(BASELINE_EE_SUBT_TOTAL_EE_SI_B6(:,8:11)),(BASELINE_EE_SUBT
_TOTAL_EE_SI_B6(:,12:17))];
BASELINE_EE_TOTAL_EC_SI_B6_substages =
[BASELINE_EE_SUBT_TOTAL_EC_SI_B6(:,1:2),sum(BASELINE_EE_SUBT_TOTAL_EC_SI_
B6(:,3:7)),sum(BASELINE_EE_SUBT_TOTAL_EC_SI_B6(:,8:11)),(BASELINE_EE_SUBT
_TOTAL_EC_SI_B6(:,12:17))];

BASELINE_EE_TOTAL_EE_NO_B6_substages =
[BASELINE_EE_SUBT_TOTAL_EE_SI_B6(:,1:2),sum(BASELINE_EE_SUBT_TOTAL_EE_SI_
B6(:,3:7)),sum(BASELINE_EE_SUBT_TOTAL_EE_SI_B6(:,8:11)),(BASELINE_EE_SUBT
_TOTAL_EE_SI_B6(:,13:17))];
```

```
BASELINE_EE_TOTAL_EC_NO_B6_substages =
[BASELINE_EE_SUBT_TOTAL_EC_SI_B6(:,1:2),sum(BASELINE_EE_SUBT_TOTAL_EC_SI_
B6(:,3:7)),sum(BASELINE_EE_SUBT_TOTAL_EC_SI_B6(:,8:11)),(BASELINE_EE_SUBT
_TOTAL_EC_SI_B6(:,13:17))];
```

RESULTS FOR CGALAN PAPER VALIDATION:

run AFProjectResultsCgalan;

CONTINUE WITH THE RESULTS:

```
save(FILE_ENV_NAME); % save the .mat file

CONTINUE_RESULTS=input('Do you want to conitnue with the result
graphs?(Y/N): ','s');
disp ' ';
disp ' ';
if CONTINUE_RESULTS(1,1) == 'Y'
    run AEProjectResults2004Mac;
else
    disp ' ';
    disp ' ';
    disp ' ';
    disp ' ';
    disp ' ';
    disp 'Thank you for using ©CRC Environmental Program.';
    disp 'Your database of materials is been saved in
"ProjectENVdata.xlsx"';
    disp ' ';
    disp ' ';
end
```

Here the fourth main program file finishes, which include the automatic execution of
other three program files, highlighted in yellow, such as transport, operational stage
and calculation matrix. All these program files will be shown below:

(4.1.p) Transport program file

FOR ROAD TRANSPORTATION

Data from EN DEFRA UK GOV TABLES & BS EN 16258-2012 for conversion factors

```
disp '4.1. TRANSPORT LOADS CALCULATIONS. LCA STAGES A4 AND C2';
disp 'The Transportation mode available is Road Good Vehicle (Truck or
Van)';
disp 'The Transport distance "Gate to Site" is assumed to be 50 miles';
disp 'The Transport distance "Site to Ladfilling site" is assumed to be
100 miles';
disp ' ';
disp ' ';

% Fuel Data from GOV UK FUEL FACTORS
FUEL_MJ_L_TTW = [35.998;32.734];
FUEL_MJ_L_WTW = [42.7;37.7];
HGV_T_KM_50 = [0.50559; 0.26929; 0.26929; 0.23057; 0.28984; 0.14278;
0.09995; 0.10441];
HGV_T_KM_100 = [0.27281; 0.15131; 0.15831; 0.13582; 0.16632; 0.08553;
0.06234; 0.06254];
% HGV_L_KM = [0.538; 0.6475; 0.7466; 0.7783; 0.822; 0.8129; 0.938;
0.9261];
HGV_L_KM = [0.538; 0.6475; 0.7466; 0.7783; 1.153647; 0.8129; 0.938;
0.9261];

VAN_T_KM = [0.61214; 0.633423; 0.502728; 0.529972];

% Distances:
KM_A4 = 55;
KM_C2 = 50;

% % FOR CAMRNE'S PAPER:
% KM_A4 = 50;
% KM_C2 = 50;
%
% if P_NAME (6) == 'R'
%     KM_A4 = 60.667;
%     KM_C2 = 55;
% elseif P_NAME (6) == 'S'
%     KM_A4 = 55;
%     KM_C2 = 50;
% end
```

Calculate Transport Loads

```
disp '(1) Heavy Good Vehicle';
disp '(2) Van Vehicle';
TGV = input ('Please define TYPE OF GOOD VEHICLE: ');
```

```matlab
if TGV == 1
    MJ_L = FUEL_MJ_L_WTW(1);
    disp ' ';
    disp ' ';
    disp '(1) Rigid < 7,5t';
    disp '(2) Rigid 7,5t < 14t';
    disp '(3) Rigid 14 < 17t';
    disp '(4) Rigid 17 < 25t';
    disp '(5) Rigid average';
    disp '(6) Artic <33t';
    disp '(7) Artic >33t';
    disp '(8) Artic average';
    HGV = input ('Please define TYPE OF HEAVY GOOD VEHICLE: ');
    disp ' ';
    disp ' ';

    if HGV == 1
        A4_GWP_T_KM = HGV_T_KM_100(1);
        C2_GWP_T_KM = HGV_T_KM_50(1);
        L_KM = HGV_L_KM (1);
        T = 7.5;
    elseif HGV == 2
        A4_GWP_T_KM = HGV_T_KM_100(2);
        C2_GWP_T_KM = HGV_T_KM_50(1);
        L_KM = HGV_L_KM (2);
        T = 14;
    elseif HGV == 3
        A4_GWP_T_KM = HGV_T_KM_100(3);
        C2_GWP_T_KM = HGV_T_KM_50(3);
        L_KM = HGV_L_KM (3);
        T = 17;
    elseif HGV == 4
        A4_GWP_T_KM = HGV_T_KM_100(4);
        C2_GWP_T_KM = HGV_T_KM_50(4);
        L_KM = HGV_L_KM (4);
        T = 25;
    elseif HGV == 5
        A4_GWP_T_KM = HGV_T_KM_100(5);
        C2_GWP_T_KM = HGV_T_KM_100(5);
        L_KM = HGV_L_KM (5);
        T = 17.5;
    elseif HGV == 6
        A4_GWP_T_KM = HGV_T_KM_100(6);
        C2_GWP_T_KM = HGV_T_KM_50(6);
        L_KM = HGV_L_KM (6);
        T = 32;
    elseif HGV == 7
        A4_GWP_T_KM = HGV_T_KM_100(7);
        C2_GWP_T_KM = HGV_T_KM_50(7);
        L_KM = HGV_L_KM (7);
```

```
        T = 35;
    else
        A4_GWP_T_KM = HGV_T_KM_100(8);
        C2_GWP_T_KM = HGV_T_KM_50(8);
        L_KM = HGV_L_KM (8);
        T = 32;
    end
else
    MJ_L = FUEL_MJ_L_WTW(1);
    disp ' ';
    disp ' ';
    VAN = input ('Please define TYPE OF VAN: ');
    disp '(1) Class I   < 1,5t';
    disp '(2) Class II  < 2,5t';
    disp '(3) Class III < 3,5t';
    disp '(4) Unknown (Average)';
    disp ' ';
    disp ' ';

    L_KM = input ('Please define FUEL CONSUMPTION (L/KM) if known: ');
L_KM_Check = exist ('L_KM','var');

if L_KM_Check == 0
    L_KM=0.45;
end

    if VAN == 1
        GWP_T_KM = VAN_T_KM(1);
        T = 1.5;
    elseif VAN == 2
        GWP_T_KM = VAN_T_KM(2);
        T = 2.5;
    elseif VAN == 3
        GWP_T_KM = VAN_T_KM(3);
        T = 3.5;
    else
        GWP_T_KM = VAN_T_KM(4);
        T = 3.5;
    end
end
```

FOR CARMEN'S PAPER:

```
% A4_GWP_T_KM = 0.17;
% C2_GWP_T_KM = 0.17;
% L_KM = 1.126;
```

Calculation

```
% in order to get total fuel L consumed:
L_A4 = KM_A4*L_KM;
```

```matlab
 L_C2 = KM_C2*L_KM;

 % GETTING FIGURES PER TONNE:
 A4_KGCO2_T = KM_A4*A4_GWP_T_KM; % TOTAL OF CO2 EMISSIONS FOR A4 PER
TONNE
 C2_KGCO2_T = KM_C2*C2_GWP_T_KM; % TOTAL OF CO2 EMISSIONS FOR C2 PER
TONNE

 % GETTING TOTAL FIGURES ***ONE TRIP***:
 A4_KGCO2 = A4_KGCO2_T*(T); % TOTAL OF CO2 EMISSIONS FOR A4 ONE TRIP
 C2_KGCO2 = C2_KGCO2_T*(T); % TOTAL OF CO2 EMISSIONS FOR C2 ONE TRIP
 A4_MJ = L_A4*MJ_L;  % TOTAL OF MJ FOR A4 ONE TRIP
 C2_MJ = L_C2*MJ_L;  % TOTAL OF MJ FOR C2 ONE TRIP

 % GETTING FIGURES PER TONNE:
 A4_MJ_T = A4_MJ/(T); % TOTAL OF MJ PER TONNE MOVED FOR A4
 C2_MJ_T = C2_MJ/(T); % TOTAL OF MJ PER TONNE MOVED FOR C2
 A4_KGCO2_T = A4_KGCO2/(T); % TOTAL OF CO2 EMISSIONS FOR A4 PER TONNE
 C2_KGCO2_T = C2_KGCO2/(T); % TOTAL OF CO2 EMISSIONS FOR C2 PER TONNE

 % GETTING FIGURES PER KG:
 A4_MJ_KG = A4_MJ_T/1000; % TOTAL OF MJ PER KG MOVED FOR A4
 C2_MJ_KG = C2_MJ_T/1000; % TOTAL OF MJ PER KG MOVED FOR C2
 A4_KGCO2_KG = A4_KGCO2_T/1000; % TOTAL OF CO2 EMISSIONS FOR A4 PER KG
MOVED
 C2_KGCO2_KG = C2_KGCO2_T/1000; % TOTAL OF CO2 EMISSIONS FOR C2 PER KG
MOVED

 % GETTING FIGURES BY tkm:
 A4_MJ_T_KM = A4_MJ/(T*KM_A4); % TOTAL OF MJ PER T·KM FOR A4
 C2_MJ_T_KM = C2_MJ/((T)*KM_C2); % TOTAL OF MJ PER T·KM FOR C2
 A4_KGCO2_T_KM = A4_KGCO2/(T*KM_A4);
 C2_KGCO2_T_KM = C2_KGCO2/((T)*KM_C2);
```

TOTAL FOR BOTH A4 AND C2 TOGETHER:

```matlab
 A4_C2_MJ_T_KM = A4_MJ_T_KM + C2_MJ_T_KM;
 A4_C2_KGCO2_T_KM = A4_KGCO2_T_KM + C2_KGCO2_T_KM;
 disp ' ';
 fprintf('ENVIRONMENTAL TRANSPORT LOADS (A4) "GATE TO SITE": %.2s
KgCO2e/tkm and %.2s MJ/tkm.\n',A4_KGCO2_T_KM,A4_MJ_T_KM);
 disp ' ';
 fprintf('ENVIRONMENTAL TRANSPORT LOADS (C2) "SITE TO LANDFILL": %.2s
KgCO2e/tkm and %.2s MJ/tkm.\n',C2_KGCO2_T_KM,C2_MJ_T_KM);
 disp ' ';
```

(4.2.p) Operational impact program file

Importing B6 if existing:

Inputing energy Demand Benchmarks if the accurate version is not known:

```
% Energy Benchmarks taken from Table 20.1-CIBSE Guide F 2012.
% It is assumed that fossil figures are indicating Natural Gas
comsunmption.

% Electricity and Gas conversion factors taken from
% Table 5.2-CIBSE GuideF-2012(section5.2.1.2:Environmental emissions
fuels_page 62):
% Gas(kW*h) to KgCO2e ratio = 0.19
% Electricity (kW*h) to KgCO2e ratio = 0.43
% Heavy fuel oil (kW*h) to KgCO2e ratio = 0.26

% Electricity and Gas conversion factors taken from DEFRA UK GOV
TABLE(2015):
% For UK Electricity Production & Transmissions are taken into account:
% Gas(kW*h) to KgCO2e ratio = 0.203
% Electricity (kW*h) to KgCO2e ratio = 0.306

% this would be column 12 in results


disp '4.2. OPERATIONAL ENERGY DEMAND. LCA STAGE B6.';
disp 'Operational Energy demand benchmark from CIBSE Guide-F/Residential
values';
disp ' ';
disp '(1) Typical Values';
disp '(2) Good Practice';
EBD=input('Please select Energy Demand Benchmark for the building: ');
disp ' ';
disp ' ';

if EBD == 1
    B6_GAS_KWH=417;
    B6_ELECT_KWH=79;
else
    B6_GAS_KWH=247;
    B6_ELECT_KWH=44;
end
```

Conversions and calculations

```
% kWh to MJ ratio = 3.6
kWh_to_MJ = 3.6;
% kWh to KgCO2e ratios:
GAS_to_KGCO2=0.206;
ELECT_to_KGCO2=0.306;
```

```matlab
 % Calculating energy:
 B6_ENERGY_KWH_M2_YEAR= (B6_GAS_KWH+B6_ELECT_KWH); % to get total energy
in kwh/m2/year
 B6_ENERGY_MJ_M2_YEAR = B6_ENERGY_KWH_M2_YEAR*kWh_to_MJ; % to get total
energy in MJ/m2/year
 B6_ENERGY_MJ_M2 = B6_ENERGY_MJ_M2_YEAR*RSP; % to get energy in MJ/m2
 B6_ENERGY_MJ = B6_ENERGY_MJ_M2*B_GIFA; % to get energy in MJ (TOTAL OF
THE BUILDING in 60 years)

 % Calculating carbon:
 B6_EMISSION_KGCO2e_M2_YEAR =
(B6_GAS_KWH*GAS_to_KGCO2)+(B6_ELECT_KWH*ELECT_to_KGCO2); % to get total
emissions in kgco2e/m2/year
 B6_EMISSION_KGCO2e_M2 = B6_EMISSION_KGCO2e_M2_YEAR*RSP; % to get total
emissions in kgCO2e/m2
 B6_EMISSION_KGCO2e = B6_EMISSION_KGCO2e_M2*B_GIFA; % to get total
emissions in kgCO2e (TOTAL OF THE BUILDING in 60 years)
 % = B6_ENERGY_KWH_M2*kWh_to_MJ,B6_KGCO2e_KWH_M2;
 clc;
 fprintf ('The Energy Demand of the building is %.2d MJ/m2/year and WGP
prediction is %.2d
KgCO2e/m2/year.\n',B6_ENERGY_MJ_M2_YEAR,B6_EMISSION_KGCO2e_M2_YEAR);
 disp ' ';
 disp ' ';
 % fprintf ('The Energy Demand of the building is %.2d kWh/m2 and %.2d
KgCO2e/m2.\n',B6_ENERGY_SUBTOTAL,B6_KGCO2e_SUBTOTAL);
 fprintf ('The Energy Demand of the building is %.2d MJ/m2 and WGP
prediction is %.2d KgCO2e/m2.\n',B6_ENERGY_MJ_M2,B6_EMISSION_KGCO2e_M2);
 disp ' ';
 disp ' ';
 fprintf ('The Energy Demand of the building is %.2d MJ and WGP
prediction is %.2d KgCO2e.\n',B6_ENERGY_MJ,B6_EMISSION_KGCO2e);
 disp ' ';
 disp ' ';
```

(4.3.p) Calculation matrix and algorithms

Generating matrix of 0 since the beginning:

```
for j=26
    specfobnum(fob+2,j)=0;
    specgfbnum(gfb+2,j)=0;
    specewbnum(ewb+2,j)=0;
    speciwbnum(iwb+2,j)=0;
    specufbnum(ufb+2,j)=0;
    specroofbnum(rb+2,j)=0;
    specwinbnum(wb+2,j)=0;
    specexdbnum(edob+2,j)=0;
    specindbnum(idob+2,j)=0;
    if T_EW ~= 1 % to get other building elements data
        specew2bnum(ew2b+2,j)=0;
        if T_EW == 3
            specew3bnum(ew3b+2,j)=0;
        end
    end
    if B_T ~= 4
        specpwbnum(pwb+2,j)=0;
        if B_T == 5
            specpw2bnum(pw2b+2,j)=0;
        end
    end

end
```

CALCULATION TRANSMITANCE OF ELEMENTS

run optimisation;

A4: TRANSPORT IMPACT OF MATERIALS USED "Trade Point to Site".

Transport is given in indicator/kg The program needs Kg/m2 the multiplication gives indicator/m2

Getting Kg/m2 of materials: Multiplying thickness (m) * density (Kg/m3).

```
fob_kg_m2=specfobnum(1:2:fob,2).*specfobnum(1:2:fob,1);
gfb_kg_m2=specgfbnum(1:2:gfb,2).*specgfbnum(1:2:gfb,1);
ewb_kg_m2=specewbnum(1:2:ewb,2).*specewbnum(1:2:ewb,1);
iwb_kg_m2=speciwbnum(1:2:iwb,2).*speciwbnum(1:2:iwb,1);

ufb_kg_m2=specufbnum(1:2:ufb,2).*specufbnum(1:2:ufb,1);
rb_kg_m2=specroofbnum(1:2:rb,2).*specroofbnum(1:2:rb,1);
wb_kg_m2=specwinbnum(1:2:wb,2).*specwinbnum(1:2:wb,1);
edob_kg_m2=specexdbnum(1:2:edob,2).*specexdbnum(1:2:edob,1);
idob_kg_m2=specindbnum(1:2:idob,2).*specindbnum(1:2:idob,1);

if T_EW ~= 1 % to get other building elements data
```

348

```
    ew2b_kg_m2=specew2bnum(1:2:ew2b,2).*specew2bnum(1:2:ew2b,1);
    if T_EW == 3
        ew3b_kg_m2=specew3bnum(1:2:ew3b,2).*specew3bnum(1:2:ew3b,1);
    end
end
if B_T ~= 4
    pwb_kg_m2=specpwbnum(1:2:pwb,2).*specpwbnum(1:2:pwb,1);
    if B_T == 5
        pw2b_kg_m2=specpw2bnum(1:2:pw2b,2).*specpw2bnum(1:2:pw2b,1);
    end
end
```

Multiplying thickness * area in order to get M3 of materials.

```
fob_m3=specfobnum(1:2:fob,1).*B_FP_A;
gfb_m3=specgfbnum(1:2:gfb,1).*B_FP_A;
ewb_m3=specewbnum(1:2:ewb,1).*B_EW_A;
iwb_m3=speciwbnum(1:2:iwb,1).*B_IW_A;
ufb_m3=specufbnum(1:2:ufb,1).*B_FP_A;
rb_m3=specroofbnum(1:2:rb,1).*B_ROOF_A;
wb_m3=specwinbnum(1:2:wb,1).*B_WIN_A;
edob_m3=specexdbnum(1:2:edob,1).*B_EDO_A;
idob_m3=specindbnum(1:2:idob,1).*B_IDO_A;

if T_EW ~= 1 % to get other building elements data
    ew2b_m3=specew2bnum(1:2:ew2b,1).*B_EW2_A;
    if T_EW == 3
        ew3b_m3=specew3bnum(1:2:ew3b,1).*B_EW3_A;
    end
end
if B_T ~= 4
    pwb_m3=specpwbnum(1:2:pwb,1).*B_PW1_A;
    if B_T == 5
        pw2b_m3=specpw2bnum(1:2:pw2b,1).*B_PW2_A;
    end
end
```

transport impact of materials BY SQM OF MATERIAL:

```
for j=8 % 2
specfobnum(1:2:fob,j)=fob_kg_m2.*A4_KGCO2_KG;
specfobnum(2:2:fob,j)=fob_kg_m2.*A4_MJ_KG;

specgfbnum(1:2:gfb,j)=gfb_kg_m2.*A4_KGCO2_KG;
specgfbnum(2:2:gfb,j)=gfb_kg_m2.*A4_MJ_KG;

specewbnum(1:2:ewb,j)=ewb_kg_m2.*A4_KGCO2_KG;
specewbnum(2:2:ewb,j)=ewb_kg_m2.*A4_MJ_KG;

speciwbnum(1:2:iwb,j)=iwb_kg_m2.*A4_KGCO2_KG;
speciwbnum(2:2:iwb,j)=iwb_kg_m2.*A4_MJ_KG;
```

```matlab
specufbnum(1:2:ufb,j)=ufb_kg_m2.*A4_KGCO2_KG;
specufbnum(2:2:ufb,j)=ufb_kg_m2.*A4_MJ_KG;


specroofbnum(1:2:rb,j)=rb_kg_m2.*A4_KGCO2_KG;
specroofbnum(2:2:rb,j)=rb_kg_m2.*A4_MJ_KG;


specwinbnum(1:2:wb,j)=wb_kg_m2.*A4_KGCO2_KG;
specwinbnum(2:2:wb,j)=wb_kg_m2.*A4_MJ_KG;


specexdbnum(1:2:edob,j)=edob_kg_m2.*A4_KGCO2_KG;
specexdbnum(2:2:edob,j)=edob_kg_m2.*A4_MJ_KG;


specindbnum(1:2:idob,j)=idob_kg_m2.*A4_KGCO2_KG;
specindbnum(2:2:idob,j)=idob_kg_m2.*A4_MJ_KG;


if T_EW ~= 1 % to get other building elements data
    specew2bnum(1:2:ew2b,j)=ew2b_kg_m2.*A4_KGCO2_KG;
    specew2bnum(2:2:ew2b,j)=ew2b_kg_m2.*A4_MJ_KG;

    if T_EW == 3
        specew3bnum(1:2:ew2b,j)=ew3b_kg_m2.*A4_KGCO2_KG;
        specew3bnum(2:2:ew2b,j)=ew3b_kg_m2.*A4_MJ_KG;
    end
end
if B_T ~= 4
    specpwbnum(1:2:pwb,j)=pwb_kg_m2.*A4_KGCO2_KG;
    specpwbnum(2:2:pwb,j)=pwb_kg_m2.*A4_MJ_KG;
    if B_T == 5
        specpw2bnum(1:2:pw2b,j)=pw2b_kg_m2.*A4_KGCO2_KG;
        specpw2bnum(2:2:pw2b,j)=pw2b_kg_m2.*A4_MJ_KG;
    end
end
end
```

A5: CONTRUCTION PROCESS IMPACT

This stage is divided into 4 sub-stages: A5_a: On-site waste (OSW) A5_b: Transport due to materials of OSW A5_c: Materials of OSW sent to landfilling (OSW_L) A5_d: Transport of materials sent to Landfilling A5_e: Construction works loads considered C1: Demolition works

First we need to get the wastage route values from the "spec...num" matrix of each BE:

ON-SITE-WASTE (OSW) percentage values:

```matlab
fob_osw=specfobnum(2:2:fob,4)./100;
gfb_osw=specgfbnum(2:2:gfb,4)./100;
ewb_osw=specewbnum(2:2:ewb,4)./100;
iwb_osw=speciwbnum(2:2:iwb,4)./100;


ufb_osw=specufbnum(2:2:ufb,4)./100;
```

```
rb_osw=specroofbnum(2:2:rb,4)./100;
wb_osw=specwinbnum(2:2:wb,4)./100;
edob_osw=specexdbnum(2:2:edob,4)./100;
idob_osw=specindbnum(2:2:idob,4)./100;

if T_EW ~= 1 % to get other building elements data
    ew2b_osw=specew2bnum(2:2:ew2b,4)./100;
    if T_EW == 3
        ew3b_osw=specew3bnum(2:2:ew3b,4)./100;
    end
end
if B_T ~= 4
    pwb_osw=specpwbnum(2:2:pwb,4)./100;
    if B_T == 5
    pw2b_osw=specpw2bnum(2:2:pw2b,4)./100;
    end
end
```

OSW-L which means ON-SITE-WASTE sent to landfilling (OSW_L) percentage values:

```
fob_osw_l=specfobnum(1:2:fob,4).*fob_osw./100;
gfb_osw_l=specgfbnum(1:2:gfb,4).*gfb_osw./100;
ewb_osw_l=specewbnum(1:2:ewb,4).*ewb_osw./100;
iwb_osw_l=speciwbnum(1:2:iwb,4).*iwb_osw./100;

ufb_osw_l=specufbnum(1:2:ufb,4).*ufb_osw./100;
rb_osw_l=specroofbnum(1:2:rb,4).*rb_osw./100;
wb_osw_l=specwinbnum(1:2:wb,4).*wb_osw./100;
edob_osw_l=specexdbnum(1:2:edob,4).*edob_osw./100;
idob_osw_l=specindbnum(1:2:idob,4).*idob_osw./100;

if T_EW ~= 1 % to get other building elements data
    ew2b_osw_l=specew2bnum(1:2:ew2b,4).*ew2b_osw./100;
    if T_EW == 3
        ew3b_osw_l=specew3bnum(1:2:ew3b,4).*ew3b_osw./100;
    end
end
if B_T ~= 4
    pwb_osw_l=specpwbnum(1:2:pwb,4).*pwb_osw./100;
    if B_T == 5
        pw2b_osw_l=specpw2bnum(1:2:pw2b,4).*pw2b_osw./100;
    end
end
```

W-L percentage values WASTE SENT TO LANDFILL:

```
fob_w_l=specfobnum(1:2:fob,4)./100;
gfb_w_l=specgfbnum(1:2:gfb,4)./100;
ewb_w_l=specewbnum(1:2:ewb,4)./100;
iwb_w_l=speciwbnum(1:2:iwb,4)./100;
```

```
ufb_w_l=specufbnum(1:2:ufb,4)./100;
rb_w_l=specroofbnum(1:2:rb,4)./100;
wb_w_l=specwinbnum(1:2:wb,4)./100;
edob_w_l=specexdbnum(1:2:edob,4)./100;
idob_w_l=specindbnum(1:2:idob,4)./100;

if T_EW ~= 1 % to get other building elements data
    ew2b_w_l=specew2bnum(1:2:ew2b,4)./100;
    if T_EW == 3
        ew3b_w_l=specew3bnum(1:2:ew3b,4)./100;
    end
end
if B_T ~= 4
    pwb_w_l=specpwbnum(1:2:pwb,4)./100;
    if B_T == 5
        pw2b_w_l=specpw2bnum(1:2:pw2b,4)./100;
    end
end
```

A5_a: Calculations OSW:

```
for j=9 % 3
specfobnum(1:2:fob,j)=fob_osw.*specfobnum(1:2:fob,7);
specfobnum(2:2:fob,j)=fob_osw.*specfobnum(2:2:fob,7);

specgfbnum(1:2:gfb,j)=gfb_osw.*specgfbnum(1:2:gfb,7);
specgfbnum(2:2:gfb,j)=gfb_osw.*specgfbnum(2:2:gfb,7);

specewbnum(1:2:ewb,j)=ewb_osw.*specewbnum(1:2:ewb,7);
specewbnum(2:2:ewb,j)=ewb_osw.*specewbnum(2:2:ewb,7);

speciwbnum(1:2:iwb,j)=iwb_osw.*speciwbnum(1:2:iwb,7);
speciwbnum(2:2:iwb,j)=iwb_osw.*speciwbnum(2:2:iwb,7);

specufbnum(1:2:ufb,j)=ufb_osw.*specufbnum(1:2:ufb,7);
specufbnum(2:2:ufb,j)=ufb_osw.*specufbnum(2:2:ufb,7);

specroofbnum(1:2:rb,j)=rb_osw.*specroofbnum(1:2:rb,7);
specroofbnum(2:2:rb,j)=rb_osw.*specroofbnum(2:2:rb,7);

specwinbnum(1:2:wb,j)=wb_osw.*specwinbnum(1:2:wb,7);
specwinbnum(2:2:wb,j)=wb_osw.*specwinbnum(2:2:wb,7);

specexdbnum(1:2:edob,j)=edob_osw.*specexdbnum(1:2:edob,7);
specexdbnum(2:2:edob,j)=edob_osw.*specexdbnum(2:2:edob,7);

specindbnum(1:2:idob,j)=idob_osw.*specindbnum(1:2:idob,7);
specindbnum(2:2:idob,j)=idob_osw.*specindbnum(2:2:idob,7);

if T_EW ~= 1 % to get other building elements data
```

```
        specew2bnum(1:2:ew2b,j)=ew2b_osw.*specew2bnum(1:2:ew2b,7);
        specew2bnum(2:2:ew2b,j)=ew2b_osw.*specew2bnum(2:2:ew2b,7);

        if T_EW == 3
            specew3bnum(1:2:ew3b,j)=ew3b_osw.*specew3bnum(1:2:ew3b,7);
            specew3bnum(2:2:ew3b,j)=ew3b_osw.*specew3bnum(2:2:ew3b,7);
        end
end
if B_T ~= 4
    specpwbnum(1:2:pwb,j)=pwb_osw.*specpwbnum(1:2:pwb,7);
    specpwbnum(2:2:pwb,j)=pwb_osw.*specpwbnum(2:2:pwb,7);
    if B_T == 5
        specpw2bnum(1:2:pw2b,j)=pw2b_osw.*specpw2bnum(1:2:pw2b,7);
        specpw2bnum(2:2:pw2b,j)=pw2b_osw.*specpw2bnum(2:2:pw2b,7);
    end
end
end
```

A5_b: Transport due to OSW Materials:

```
for j=10 % 4
specfobnum(1:2:fob,j)=fob_kg_m2.*fob_osw.*A4_KGCO2_KG;
specfobnum(2:2:fob,j)=fob_kg_m2.*fob_osw.*A4_MJ_KG;

specgfbnum(1:2:gfb,j)=gfb_kg_m2.*gfb_osw.*A4_KGCO2_KG;
specgfbnum(2:2:gfb,j)=gfb_kg_m2.*gfb_osw.*A4_MJ_KG;

specewbnum(1:2:ewb,j)=ewb_kg_m2.*ewb_osw.*A4_KGCO2_KG;
specewbnum(2:2:ewb,j)=ewb_kg_m2.*ewb_osw.*A4_MJ_KG;

speciwbnum(1:2:iwb,j)=iwb_kg_m2.*iwb_osw.*A4_KGCO2_KG;
speciwbnum(2:2:iwb,j)=iwb_kg_m2.*iwb_osw.*A4_MJ_KG;

specufbnum(1:2:ufb,j)=ufb_kg_m2.*ufb_osw.*A4_KGCO2_KG;
specufbnum(2:2:ufb,j)=ufb_kg_m2.*ufb_osw.*A4_MJ_KG;

specroofbnum(1:2:rb,j)=rb_kg_m2.*rb_osw.*A4_KGCO2_KG;
specroofbnum(2:2:rb,j)=rb_kg_m2.*rb_osw.*A4_MJ_KG;

specwinbnum(1:2:wb,j)=wb_kg_m2.*wb_osw.*A4_KGCO2_KG;
specwinbnum(2:2:wb,j)=wb_kg_m2.*wb_osw.*A4_MJ_KG;

specexdbnum(1:2:edob,j)=edob_kg_m2.*edob_osw.*A4_KGCO2_KG;
specexdbnum(2:2:edob,j)=edob_kg_m2.*edob_osw.*A4_MJ_KG;

specindbnum(1:2:idob,j)=idob_kg_m2.*idob_osw.*A4_KGCO2_KG;
specindbnum(2:2:idob,j)=idob_kg_m2.*idob_osw.*A4_MJ_KG;

if T_EW ~= 1 % to get other building elements data
    specew2bnum(1:2:ew2b,j)=ew2b_kg_m2.*ew2b_osw.*A4_KGCO2_KG;
```

```
    specew2bnum(2:2:ew2b,j)=ew2b_kg_m2.*ew2b_osw.*A4_MJ_KG;
    if T_EW == 3
        specew3bnum(1:2:ew3b,j)=ew3b_kg_m2.*ew3b_osw.*A4_KGCO2_KG;
        specew3bnum(2:2:ew3b,j)=ew3b_kg_m2.*ew3b_osw.*A4_MJ_KG;
    end
end

if B_T ~= 4
    specpwbnum(1:2:pwb,j)=pwb_kg_m2.*pwb_osw.*A4_KGCO2_KG;
    specpwbnum(2:2:pwb,j)=pwb_kg_m2.*pwb_osw.*A4_MJ_KG;
    if B_T == 5
        specpw2bnum(1:2:pw2b,j)=pw2b_kg_m2.*pw2b_osw.*A4_KGCO2_KG;
        specpw2bnum(2:2:pw2b,j)=pw2b_kg_m2.*pw2b_osw.*A4_MJ_KG;
    end
end
end
```

A5_c: OSW_L Materials:

Construction waste % that is sent to landfilling. if the on site construction waste for a material is 5% and the percentage sent to landfilling site is the 90% of that waste that means that the 4,5 % of the material is wasted on landfilling sites.

```
for j=11 % 5
specfobnum(1:2:fob,j)=specfobnum(1:2:fob,7).*fob_osw_l;
specfobnum(2:2:fob,j)=specfobnum(2:2:fob,7).*fob_osw_l;

specgfbnum(1:2:gfb,j)=specgfbnum(1:2:gfb,7).*gfb_osw_l;
specgfbnum(2:2:gfb,j)=specgfbnum(2:2:gfb,7).*gfb_osw_l;

specewbnum(1:2:ewb,j)=specewbnum(1:2:ewb,7).*ewb_osw_l;
specewbnum(2:2:ewb,j)=specewbnum(2:2:ewb,7).*ewb_osw_l;

speciwbnum(1:2:iwb,j)=speciwbnum(1:2:iwb,7).*iwb_osw_l;
speciwbnum(2:2:iwb,j)=speciwbnum(2:2:iwb,7).*iwb_osw_l;

specufbnum(1:2:ufb,j)=specufbnum(1:2:ufb,7).*ufb_osw_l;
specufbnum(2:2:ufb,j)=specufbnum(2:2:ufb,7).*ufb_osw_l;

specroofbnum(1:2:rb,j)=specroofbnum(1:2:rb,7).*rb_osw_l;
specroofbnum(2:2:rb,j)=specroofbnum(2:2:rb,7).*rb_osw_l;

specwinbnum(1:2:wb,j)=specwinbnum(1:2:wb,7).*wb_osw_l;
specwinbnum(2:2:wb,j)=specwinbnum(2:2:wb,7).*wb_osw_l;

specexdbnum(1:2:edob,j)=specexdbnum(1:2:edob,7).*edob_osw_l;
specexdbnum(2:2:edob,j)=specexdbnum(2:2:edob,7).*edob_osw_l;

specindbnum(1:2:idob,j)=specindbnum(1:2:idob,7).*idob_osw_l;
specindbnum(2:2:idob,j)=specindbnum(2:2:idob,7).*idob_osw_l;
```

```
if T_EW ~= 1 % to get other building elements data
    specew2bnum(1:2:ew2b,j)=specew2bnum(1:2:ew2b,7).*ew2b_osw_l;
    specew2bnum(2:2:ew2b,j)=specew2bnum(2:2:ew2b,7).*ew2b_osw_l;
    if T_EW == 3
        specew3bnum(1:2:ew3b,j)=specew3bnum(1:2:ew3b,7).*ew3b_osw_l;
        specew3bnum(2:2:ew3b,j)=specew3bnum(2:2:ew3b,7).*ew3b_osw_l;
    end
end

if B_T ~= 4
    specpwbnum(1:2:pwb,j)=specpwbnum(1:2:pwb,7).*pwb_osw_l;
    specpwbnum(2:2:pwb,j)=specpwbnum(2:2:pwb,7).*pwb_osw_l;
    if B_T == 5
        specpw2bnum(1:2:pw2b,j)=specpw2bnum(1:2:pw2b,7).*pw2b_osw_l;
        specpw2bnum(2:2:pw2b,j)=specpw2bnum(2:2:pw2b,7).*pw2b_osw_l;
    end
end
end
```

A5_d: Transport due to OSW_L Materials:

```
for j=12 % 6
specfobnum(1:2:fob,j)=fob_kg_m2.*fob_osw_l.*C2_KGCO2_KG;
specfobnum(2:2:fob,j)=fob_kg_m2.*fob_osw_l.*C2_MJ_KG;

specgfbnum(1:2:gfb,j)=gfb_kg_m2.*gfb_osw_l.*C2_KGCO2_KG;
specgfbnum(2:2:gfb,j)=gfb_kg_m2.*gfb_osw_l.*C2_MJ_KG;

specewbnum(1:2:ewb,j)=ewb_kg_m2.*ewb_osw_l.*C2_KGCO2_KG;
specewbnum(2:2:ewb,j)=ewb_kg_m2.*ewb_osw_l.*C2_MJ_KG;

speciwbnum(1:2:iwb,j)=iwb_kg_m2.*iwb_osw_l.*C2_KGCO2_KG;
speciwbnum(2:2:iwb,j)=iwb_kg_m2.*iwb_osw_l.*C2_MJ_KG;

specufbnum(1:2:ufb,j)=ufb_kg_m2.*ufb_osw_l.*C2_KGCO2_KG;
specufbnum(2:2:ufb,j)=ufb_kg_m2.*ufb_osw_l.*C2_MJ_KG;

specroofbnum(1:2:rb,j)=rb_kg_m2.*rb_osw_l.*C2_KGCO2_KG;
specroofbnum(2:2:rb,j)=rb_kg_m2.*rb_osw_l.*C2_MJ_KG;

specwinbnum(1:2:wb,j)=wb_kg_m2.*wb_osw_l.*C2_KGCO2_KG;
specwinbnum(2:2:wb,j)=wb_kg_m2.*wb_osw_l.*C2_MJ_KG;

specexdbnum(1:2:edob,j)=edob_kg_m2.*edob_osw_l.*C2_KGCO2_KG;
specexdbnum(2:2:edob,j)=edob_kg_m2.*edob_osw_l.*C2_MJ_KG;

specindbnum(1:2:idob,j)=idob_kg_m2.*idob_osw_l.*C2_KGCO2_KG;
specindbnum(2:2:idob,j)=idob_kg_m2.*idob_osw_l.*C2_MJ_KG;

if T_EW ~= 1 % to get other building elements data
```

```
    specew2bnum(1:2:ew2b,j)=ew2b_kg_m2.*ew2b_osw_l.*C2_KGCO2_KG;
    specew2bnum(2:2:ew2b,j)=ew2b_kg_m2.*ew2b_osw_l.*C2_MJ_KG;
    if T_EW == 3
        specew3bnum(1:2:ew3b,j)=ew3b_kg_m2.*ew3b_osw_l.*C2_KGCO2_KG;
        specew3bnum(2:2:ew3b,j)=ew3b_kg_m2.*ew3b_osw_l.*C2_MJ_KG;
    end
end

if B_T ~= 4
    specpwbnum(1:2:pwb,j)=pwb_kg_m2.*pwb_osw_l.*C2_KGCO2_KG;
    specpwbnum(2:2:pwb,j)=pwb_kg_m2.*pwb_osw_l.*C2_MJ_KG;
    if B_T == 5
        specpw2bnum(1:2:pw2b,j)=pw2b_kg_m2.*pw2b_osw_l.*C2_KGCO2_KG;
        specpw2bnum(2:2:pw2b,j)=pw2b_kg_m2.*pw2b_osw_l.*C2_MJ_KG;
    end
end
end
```

A5_e: Construction works energy and CO2 emissions

```
% 2010-Life Cycle primary energy used and carbon emissions of 8-storey
building
% demolition:
% CONSTRUCTION:
% EE=80 kWh/m2 = 288 MJ/m2 of building
% EC=27 KgCO2e/m2 of building

% 2009-A Methodology for predicting the severity of environmental impacts
% related to the construction process
% From this paper we know that average weight of a building is
1514,07kg/m2

% Using both papers we have that:
% CONSTRUCTION:
% EE=0,19 MJ/Kg of material
% EC=0,018 KgCO2e/Kg of material

% CONS_EE = 288; % MJ/m2
% CONS_EC = 27; % KgCO2e/m2
%
% B_CONS_EE = CONS_EE*B_GIFA;
% B_CONS_EC = CONS_EC*B_GIFA;
% B_CONS_ALL = [B_CONS_EE;B_CONS_EC];
```

FOR VALIDATION OF THE TOOL USING FIGURES per kg of material:

(FOR PAPER WITH C.GALAN WILL USE FIGURE PER M3 OF MATERIAL)

```
EW1_kg = sum(ewb_kg_m2*B_EW_A);
EW_kg_total = EW1_kg;
```

```
if T_EW ~= 1
    EW2_kg = sum(ew2b_kg_m2*B_EW2_A);
%     B_EW_A_TOTAL = B_EW_A+B_EW2_A;
    EW_kg_total = EW1_kg+EW2_kg;
    if T_EW == 3
    EW3_kg = sum(ewb_kg_m2*B_EW3_A);
%     B_EW_A_TOTAL = B_EW_A+B_EW2_A+B_EW3_A;
    EW_kg_total = EW1_kg+EW2_kg+EW3_kg;
    end
end
%
% B_CONS_EE = CONS_EE_MJ_kg*EW_kg_total;
% B_CONS_EC = CONS_EC_KGCO2e_kg*EW_kg_total;
% B_CONS_ALL = [B_CONS_EE;B_CONS_EC];
%
% A5_B_MJ = CONS_EE_MJ_kg*EW_kg_total;
% A5_B_KgCO2 = CONS_EC_KGCO2e_kg*EW_kg_total;
```

FOR VALIDATION WITH CGALAN PAPER - per m3 of material:

Following Kemperberger we have the following table: A5_MJ_M3 = ["Primary Energy consumption","MJ/m3 material", "MJ/m3 building"; "Construction", 481, 72.15; "Refurbishment", 741, 111.15; "Demolition", 370, 55.5; "Subtotal", 1222, 183.3; "-Diesel 70%", 855, 128.25; "-Electricity 30%", 136, 20.4];

```
MJ_M3_num = [481, 72.15;
    741, 111.15;
    370, 55.5;
    1222, 183.3;
    855.4, 128.25;
    136.06, 20.4];

% GETTING FIGURES FOR A5+C1 STAGE: MJ & KGCO2e:
% CONS_DEM_EE_MJ_m3 = MJ_M3_num (5,1)+MJ_M3_num (6,1); % MJ/m3
CONS_REF_EE_MJ_m3_diesel = MJ_M3_num (5,1); % MJ/m3 due to diesel on site
CONS_REF_EE_MJ_m3_elect = MJ_M3_num (6,1); % MJ/m3 due to electricity on
site
CONS_REF_EE_KWH_m3_elect = MJ_M3_num (6,1)/3.6; % kWh/m3 due to elect. on
site
```

CONVERSION UNITS FROM DIESEL CONSUMED TO KGCO2e AND CED(MJ).

```
CONVERSIONS = [0.09096, 1.37992;
               0.50038, 10.90376];

% RATIO DIESEL:                     0,09 KGCO2e/MJ & 1,38 MJ(CED)/MJ
% RATIO ELECTRICITY (SPAIN MIX):   0,5 KGCO2e/kWh & 10,9 MJ(CED)/kWh
% RATIO ELECTRICITY (UK MIX):      0,306 KGCO2e/kWh & 10,9 MJ(CED)/kWh

% KgCO2e:
```

```
CONS_REF_EC_KGCO2e_m3_diesel = CONS_REF_EE_MJ_m3_diesel *
CONVERSIONS(1,1); % KgCO2e/m3  due to on-site diesel
CONS_REF_EC_KGCO2e_m3_elect = CONS_REF_EE_KWH_m3_elect *
CONVERSIONS(2,1); % KgCO2e/m3 due to on-site electricity
CONS_REF_EC_KGCO2e_m3 = CONS_REF_EC_KGCO2e_m3_diesel +
CONS_REF_EC_KGCO2e_m3_elect ; % KgCO2e/m3 due to on-site electricity &
diesel combined

CONS_REF_CED_MJ_m3_diesel = CONS_REF_EE_MJ_m3_diesel * CONVERSIONS(1,2);
% (CED) MJ/m3  due to on-site diesel
CONS_REF_CED_MJ_m3_elect = CONS_REF_EE_KWH_m3_elect * CONVERSIONS(2,2); %
(CED) MJ/m3 due to on-site electricity
CONS_REF_CED_MJ_m3 = CONS_REF_CED_MJ_m3_diesel + CONS_REF_CED_MJ_m3_elect
; % (CED) MJ/m3 due to on-site electricity & diesel combined
```

ADDING UP ALL M3 OF MATERIALS FROM EXTERNAL WALLS:

```
EW1_m3 = sum(ewb_m3);
EW_m3_total = EW1_m3;

if T_EW ~= 1
    EW2_m3 = sum(ew2b_m3);
%    B_EW_A_TOTAL = B_EW_A+B_EW2_A;
    EW_m3_total = EW1_m3+EW2_m3;
    if T_EW == 3
    EW3_m3 = sum(ew3b_m3);
%    B_EW_A_TOTAL = B_EW_A+B_EW2_A+B_EW3_A;
    EW_m3_total = EW1_m3+EW2_m3+EW3_m3;
    end
end
```

INPUTTING ALL M3 OF OPTIONS MANUALLY:

```
run 'LCA_calculation_EW_M3_total';
```

GETTING TOTALS MULTIPLYING TOTAL M3 BY INDICATOR/M3.

GETTING TOTALS OF MJ (CED) & KgCO2e:

```
B_CONS_REF_EE = CONS_REF_CED_MJ_m3*EW_m3_total;
B_CONS_REF_EC = CONS_REF_EC_KGCO2e_m3*EW_m3_total;
```

GETTING MJ BY TYPE OF FUEL:

```
B_CONS_REF_EE_MJ_diesel = CONS_REF_CED_MJ_m3_diesel*EW_m3_total; % MJ/m3
from diesel
B_CONS_REF_EE_MJ_elect = CONS_REF_CED_MJ_m3_elect*EW_m3_total; % MJ/m3
from eletricity

% GETTING KGCO2e BY TYPE OF FUEL:
B_CONS_REF_EC_KGCO2e_diesel = CONS_REF_EC_KGCO2e_m3_diesel*EW_m3_total;
B_CONS_REF_EC_KGCO2e_elect = CONS_REF_EC_KGCO2e_m3_elect*EW_m3_total;
```

```
% getting globals:
B_CONS_ALL = [B_CONS_REF_EE;B_CONS_REF_EC];

A5_B_MJ = B_CONS_REF_EE;
A5_B_KgCO2 = B_CONS_REF_EC;
for j=13 % 7
specfobnum(1:fob,j)=0;
specgfbnum(1:gfb,j)=0;
specewbnum(1:ewb,j)=0;
speciwbnum(1:iwb,j)=0;
specufbnum(1:ufb,j)=0;
specroofbnum(1:rb,j)=0;
specwinbnum(1:wb,j)=0;
specexdbnum(1:edob,j)=0;
specindbnum(1:idob,j)=0;

if T_EW ~= 1 % to get other building elements data
    specew2bnum(1:ew2b,j)=0;
    if T_EW == 3
        specew3bnum(1:ew3b,j)=0;
    end
end

if B_T ~= 4
    specpwbnum(1:pwb,j)=0;
    if B_T == 5
        specpw2bnum(1:pw2b,j)=0;
    end
end
end
```

B4: Replacements.

write in "spec...num" files the number of Replacements just below the Required Service
Live (RSL) Columns: 3a=RSL, 3b=No of replacement, 7=A1-A3, 8=A4, 9=A5_a, 10=A5_b,
11=A5_c, 12=A5_d.

```
for j=3
    specfobnum(2:2:fob,j)=(ceil(RSP./specfobnum(1:2:fob,j)))-1;
    fob_rep = specfobnum(2:2:fob,j);
    specgfbnum(2:2:gfb,j)=(ceil(RSP./specgfbnum(1:2:gfb,j)))-1;
    gfb_rep = specgfbnum(2:2:gfb,j);
    specewbnum(2:2:ewb,j)=(ceil(RSP./specewbnum(1:2:ewb,j)))-1;
    ewb_rep = specewbnum(2:2:ewb,j);
    speciwbnum(2:2:iwb,j)=(ceil(RSP./speciwbnum(1:2:iwb,j)))-1;
    iwb_rep = speciwbnum(2:2:iwb,j);
    specufbnum(2:2:ufb,j)=(ceil(RSP./specufbnum(1:2:ufb,j)))-1;
    ufb_rep = specufbnum(2:2:ufb,j);
    specroofbnum(2:2:rb,j)=(ceil(RSP./specroofbnum(1:2:rb,j)))-1;
    rb_rep = specroofbnum(2:2:rb,j);
```

```
    specwinbnum(2:2:wb,j)=(ceil(RSP./specwinbnum(1:2:wb,j)))-1;
    wb_rep = specwinbnum(2:2:wb,j);
    specexdbnum(2:2:edob,j)=(ceil(RSP./specexdbnum(1:2:edob,j)))-1;
    edob_rep = specexdbnum(2:2:edob,j);
    specindbnum(2:2:idob,j)=(ceil(RSP./specindbnum(1:2:idob,j)))-1;
    idob_rep = specindbnum(2:2:idob,j);

    if T_EW ~= 1 % to get other building elements data
        specew2bnum(2:2:ew2b,j)=(ceil(RSP./specew2bnum(1:2:ew2b,j)))-1;
        ew2b_rep = specew2bnum(2:2:ew2b,j);
        if T_EW == 3
            specew3bnum(2:2:ew3b,j)=(ceil(RSP./specew3bnum(1:2:ew3b,j)))-
1;
            ew3b_rep = specew3bnum(2:2:ew3b,j);
        end
    end

    if B_T ~= 4
        specpwbnum(2:2:pwb,j)=(ceil(RSP./specpwbnum(1:2:pwb,j)))-1;
        pwb_rep = specpwbnum(2:2:pwb,j);
        if B_T == 5
            specpw2bnum(2:2:pw2b,j)=(ceil(RSP./specpw2bnum(1:2:pw2b,j)))-
1;
            pw2b_rep = specpw2bnum(2:2:pw2b,j);
        end
    end
end
```

B4_a: Materials for replacement: (Manufacturing+OSW)*N.Replacements &

```
for j=14 % 8
specfobnum(1:2:fob,j)=fob_rep.*((1+fob_osw).*specfobnum(1:2:fob,j-6));
specfobnum(2:2:fob,j)=fob_rep.*((1+fob_osw).*specfobnum(2:2:fob,j-6));

specgfbnum(1:2:gfb,j)=gfb_rep.*((1+gfb_osw).*specgfbnum(1:2:gfb,j-6));
specgfbnum(2:2:gfb,j)=gfb_rep.*((1+gfb_osw).*specgfbnum(2:2:gfb,j-6));

specewbnum(1:2:ewb,j)=ewb_rep.*((1+ewb_osw).*specewbnum(1:2:ewb,j-6));
specewbnum(2:2:ewb,j)=ewb_rep.*((1+ewb_osw).*specewbnum(2:2:ewb,j-6));

speciwbnum(1:2:iwb,j)=iwb_rep.*((1+iwb_osw).*speciwbnum(1:2:iwb,j-6));
speciwbnum(2:2:iwb,j)=iwb_rep.*((1+iwb_osw).*speciwbnum(2:2:iwb,j-6));

specufbnum(1:2:ufb,j)=ufb_rep.*((1+ufb_osw).*specufbnum(1:2:ufb,j-6));
specufbnum(2:2:ufb,j)=ufb_rep.*((1+ufb_osw).*specufbnum(2:2:ufb,j-6));

specroofbnum(1:2:rb,j)=rb_rep.*((1+rb_osw).*specroofbnum(1:2:rb,j-6));
specroofbnum(2:2:rb,j)=rb_rep.*((1+rb_osw).*specroofbnum(2:2:rb,j-6));

specwinbnum(1:2:wb,j)=wb_rep.*((1+wb_osw).*specwinbnum(1:2:wb,j-6));
```

```
specwinbnum(2:2:wb,j)=wb_rep.*((1+wb_osw).*specwinbnum(2:2:wb,j-6));

specexdbnum(1:2:edob,j)=edob_rep.*((edob_osw).*specexdbnum(1:2:edob,j-
6));
specexdbnum(2:2:edob,j)=edob_rep.*((edob_osw).*specexdbnum(2:2:edob,j-
6));

specindbnum(1:2:idob,j)=idob_rep.*((idob_osw).*specindbnum(1:2:idob,j-
6));
specindbnum(2:2:idob,j)=idob_rep.*((idob_osw).*specindbnum(2:2:idob,j-
6));

if T_EW ~= 1 % to get other building elements data

specew2bnum(1:2:ew2b,j)=ew2b_rep.*((1+ew2b_osw).*specew2bnum(1:2:ew2b,j-
6));

specew2bnum(2:2:ew2b,j)=ew2b_rep.*((1+ew2b_osw).*specew2bnum(2:2:ew2b,j-
6));
    if T_EW == 3

specew3bnum(1:2:ew3b,j)=ew3b_rep.*((1+ew3b_osw).*specew3bnum(1:2:ew3b,j-
6));

specew3bnum(2:2:ew3b,j)=ew3b_rep.*((1+ew3b_osw).*specew3bnum(2:2:ew3b,j-
6));
    end
end

if B_T ~= 4
    specpwbnum(1:2:pwb,j)=pwb_rep.*((1+pwb_osw).*specpwbnum(1:2:pwb,j-
6));
    specpwbnum(2:2:pwb,j)=pwb_rep.*((1+pwb_osw).*specpwbnum(2:2:pwb,j-
6));
    if B_T == 5

specpw2bnum(1:2:pw2b,j)=pw2b_rep.*((1+pw2b_osw).*specpw2bnum(1:2:pw2b,j-
6));

specpw2bnum(2:2:pw2b,j)=pw2b_rep.*((1+pw2b_osw).*specpw2bnum(2:2:pw2b,j-
6));
    end
end
end
```

B4_b: Transport "Gate to Site" for replacement: N.Replacements*(Manufacturing+OSW)

```
for j=15 % 9
specfobnum(1:2:fob,j)=fob_rep.*((1+fob_osw).*specfobnum(1:2:fob,j-6));
specfobnum(2:2:fob,j)=fob_rep.*((1+fob_osw).*specfobnum(2:2:fob,j-6));
```

```
specgfbnum(1:2:gfb,j)=gfb_rep.*((1+gfb_osw).*specgfbnum(1:2:gfb,j-6));
specgfbnum(2:2:gfb,j)=gfb_rep.*((1+gfb_osw).*specgfbnum(2:2:gfb,j-6));

specewbnum(1:2:ewb,j)=ewb_rep.*((1+ewb_osw).*specewbnum(1:2:ewb,j-6));
specewbnum(2:2:ewb,j)=ewb_rep.*((1+ewb_osw).*specewbnum(2:2:ewb,j-6));

speciwbnum(1:2:iwb,j)=iwb_rep.*((1+iwb_osw).*speciwbnum(1:2:iwb,j-6));
speciwbnum(2:2:iwb,j)=iwb_rep.*((1+iwb_osw).*speciwbnum(2:2:iwb,j-6));

specufbnum(1:2:ufb,j)=ufb_rep.*((1+ufb_osw).*specufbnum(1:2:ufb,j-6));
specufbnum(2:2:ufb,j)=ufb_rep.*((1+ufb_osw).*specufbnum(2:2:ufb,j-6));

specroofbnum(1:2:rb,j)=rb_rep.*((1+rb_osw).*specroofbnum(1:2:rb,j-6));
specroofbnum(2:2:rb,j)=rb_rep.*((1+rb_osw).*specroofbnum(2:2:rb,j-6));

specwinbnum(1:2:wb,j)=wb_rep.*((1+wb_osw).*specwinbnum(1:2:wb,j-6));
specwinbnum(2:2:wb,j)=wb_rep.*((1+wb_osw).*specwinbnum(2:2:wb,j-6));

specexdbnum(1:2:edob,j)=edob_rep.*((1+edob_osw).*specexdbnum(1:2:edob,j-
6));
specexdbnum(2:2:edob,j)=edob_rep.*((1+edob_osw).*specexdbnum(2:2:edob,j-
6));

specindbnum(1:2:idob,j)=idob_rep.*((1+idob_osw).*specindbnum(1:2:idob,j-
6));
specindbnum(2:2:idob,j)=idob_rep.*((1+idob_osw).*specindbnum(2:2:idob,j-
6));

if T_EW ~= 1 % to get other building elements data

specew2bnum(1:2:ew2b,j)=ew2b_rep.*((1+ew2b_osw).*specew2bnum(1:2:ew2b,j-
6));

specew2bnum(2:2:ew2b,j)=ew2b_rep.*((1+ew2b_osw).*specew2bnum(2:2:ew2b,j-
6));
    if T_EW == 3

specew3bnum(1:2:ew3b,j)=ew3b_rep.*((1+ew3b_osw).*specew3bnum(1:2:ew3b,j-
6));

specew3bnum(2:2:ew3b,j)=ew3b_rep.*((1+ew3b_osw).*specew3bnum(2:2:ew3b,j-
6));
    end
end

if B_T ~= 4
    specpwbnum(1:2:pwb,j)=pwb_rep.*((1+pwb_osw).*specpwbnum(1:2:pwb,j-
6));
```

```
    specpwbnum(2:2:pwb,j)=pwb_rep.*((1+pwb_osw).*specpwbnum(2:2:pwb,j-
6));
    if B_T == 5

specpw2bnum(1:2:pw2b,j)=pw2b_rep.*((1+pw2b_osw).*specpw2bnum(1:2:pw2b,j-
6));

specpw2bnum(2:2:pw2b,j)=pw2b_rep.*((1+pw2b_osw).*specpw2bnum(2:2:pw2b,j-
6));
    end
end
end
```

B4_c: Materials replacement to landfill: N.Replacements*Material*(W_L)

For mass quantities calculations: for environmental calculations:

```
for j=16 % 10
specfobnum(1:2:fob,j)=fob_rep.*(1+fob_osw).*specfobnum(1:2:fob,7).*fob_w_
l;
specfobnum(2:2:fob,j)=fob_rep.*(1+fob_osw).*specfobnum(2:2:fob,7).*fob_w_
l;

specgfbnum(1:2:gfb,j)=gfb_rep.*(1+gfb_osw).*specgfbnum(1:2:gfb,7).*gfb_w_
l;
specgfbnum(2:2:gfb,j)=gfb_rep.*(1+gfb_osw).*specgfbnum(2:2:gfb,7).*gfb_w_
l;

specewbnum(1:2:ewb,j)=ewb_rep.*(1+ewb_osw).*specewbnum(1:2:ewb,7).*ewb_w_
l;
specewbnum(2:2:ewb,j)=ewb_rep.*(1+ewb_osw).*specewbnum(2:2:ewb,7).*ewb_w_
l;

speciwbnum(1:2:iwb,j)=iwb_rep.*(1+iwb_osw).*speciwbnum(1:2:iwb,7).*iwb_w_
l;
speciwbnum(2:2:iwb,j)=iwb_rep.*(1+iwb_osw).*speciwbnum(2:2:iwb,7).*iwb_w_
l;

specufbnum(1:2:ufb,j)=ufb_rep.*(1+ufb_osw).*specufbnum(1:2:ufb,7).*ufb_w_
l;
specufbnum(2:2:ufb,j)=ufb_rep.*(1+ufb_osw).*specufbnum(2:2:ufb,7).*ufb_w_
l;

specroofbnum(1:2:rb,j)=rb_rep.*(1+rb_osw).*specroofbnum(1:2:rb,7).*rb_w_l
;
specroofbnum(2:2:rb,j)=rb_rep.*(1+rb_osw).*specroofbnum(2:2:rb,7).*rb_w_l
;

specwinbnum(1:2:wb,j)=wb_rep.*(1+wb_osw).*specwinbnum(1:2:wb,7).*wb_w_l;
specwinbnum(2:2:wb,j)=wb_rep.*(1+wb_osw).*specwinbnum(2:2:wb,7).*wb_w_l;
```

```
specexdbnum(1:2:edob,j)=edob_rep.*(1+edob_osw).*specexdbnum(1:2:edob,7).*
edob_w_l;
specexdbnum(2:2:edob,j)=edob_rep.*(1+edob_osw).*specexdbnum(2:2:edob,7).*
edob_w_l;

specindbnum(1:2:idob,j)=idob_rep.*(1+idob_osw).*specindbnum(1:2:idob,7).*
idob_w_l;
specindbnum(2:2:idob,j)=idob_rep.*(1+idob_osw).*specindbnum(2:2:idob,7).*
idob_w_l;

if T_EW ~= 1 % to get other building elements data

specew2bnum(1:2:ew2b,j)=ew2b_rep.*(1+ew2b_osw).*specew2bnum(1:2:ew2b,7).*
ew2b_w_l;

specew2bnum(2:2:ew2b,j)=ew2b_rep.*(1+ew2b_osw).*specew2bnum(2:2:ew2b,7).*
ew2b_w_l;
    if T_EW == 3

specew3bnum(1:2:ew3b,j)=ew3b_rep.*(1+ew3b_osw).*specew3bnum(1:2:ew3b,7).*
ew3b_w_l;

specew3bnum(2:2:ew3b,j)=ew3b_rep.*(1+ew3b_osw).*specew3bnum(2:2:ew3b,7).*
ew3b_w_l;
    end
end

if B_T ~= 4

specpwbnum(1:2:pwb,j)=pwb_rep.*(1+pwb_osw).*specpwbnum(1:2:pwb,7).*pwb_w_
l;

specpwbnum(2:2:pwb,j)=pwb_rep.*(1+pwb_osw).*specpwbnum(2:2:pwb,7).*pwb_w_
l;
    if B_T == 5

specpw2bnum(1:2:pw2b,j)=pw2b_rep.*(1+pw2b_osw).*specpw2bnum(1:2:pw2b,7).*
pw2b_w_l;

specpw2bnum(2:2:pw2b,j)=pw2b_rep.*(1+pw2b_osw).*specpw2bnum(2:2:pw2b,7).*
pw2b_w_l;
    end
end
end
```

B4_d: Transport to disposal of replacement: (Transport-OSW_L)*N.Replacements

```
for j=17 % 11
```

```
specfobnum(1:2:fob,j)=fob_rep.*fob_kg_m2.*(1+fob_osw).*fob_w_l.*C2_KGCO2_
KG;
specfobnum(2:2:fob,j)=fob_rep.*fob_kg_m2.*(1+fob_osw).*fob_w_l.*C2_MJ_KG;

specgfbnum(1:2:gfb,j)=gfb_rep.*gfb_kg_m2.*(1+gfb_osw).*gfb_w_l.*C2_KGCO2_
KG;
specgfbnum(2:2:gfb,j)=gfb_rep.*gfb_kg_m2.*(1+gfb_osw).*gfb_w_l.*C2_MJ_KG;

specewbnum(1:2:ewb,j)=ewb_rep.*ewb_kg_m2.*(1+ewb_osw).*ewb_w_l.*C2_KGCO2_
KG;
specewbnum(2:2:ewb,j)=ewb_rep.*ewb_kg_m2.*(1+ewb_osw).*ewb_w_l.*C2_MJ_KG;

speciwbnum(1:2:iwb,j)=iwb_rep.*iwb_kg_m2.*(1+iwb_osw).*iwb_w_l.*C2_KGCO2_
KG;
speciwbnum(2:2:iwb,j)=iwb_rep.*iwb_kg_m2.*(1+iwb_osw).*iwb_w_l.*C2_MJ_KG;

specufbnum(1:2:ufb,j)=ufb_rep.*ufb_kg_m2.*(1+ufb_osw).*ufb_w_l.*C2_KGCO2_
KG;
specufbnum(2:2:ufb,j)=ufb_rep.*ufb_kg_m2.*(1+ufb_osw).*ufb_w_l.*C2_MJ_KG;

specroofbnum(1:2:rb,j)=rb_rep.*rb_kg_m2.*(1+rb_osw).*rb_w_l.*C2_KGCO2_KG;
specroofbnum(2:2:rb,j)=rb_rep.*rb_kg_m2.*(1+rb_osw).*rb_w_l.*C2_MJ_KG;

specwinbnum(1:2:wb,j)=wb_rep.*wb_kg_m2.*(1+wb_osw).*wb_w_l.*C2_KGCO2_KG;
specwinbnum(2:2:wb,j)=wb_rep.*wb_kg_m2.*(1+wb_osw).*wb_w_l.*C2_MJ_KG;

specexdbnum(1:2:edob,j)=edob_rep.*edob_kg_m2.*(1+edob_osw).*edob_w_l.*C2_
KGCO2_KG;
specexdbnum(2:2:edob,j)=edob_rep.*edob_kg_m2.*(1+edob_osw).*edob_w_l.*C2_
MJ_KG;

specindbnum(1:2:idob,j)=idob_rep.*idob_kg_m2.*(1+idob_osw).*idob_w_l.*C2_
KGCO2_KG;
specindbnum(2:2:idob,j)=idob_rep.*idob_kg_m2.*(1+idob_osw).*idob_w_l.*C2_
MJ_KG;

if T_EW ~= 1 % to get other building elements data

specew2bnum(1:2:ew2b,j)=ew2b_rep.*ew2b_kg_m2.*(1+ew2b_osw).*ew2b_w_l.*C2_
KGCO2_KG;

specew2bnum(2:2:ew2b,j)=ew2b_rep.*ew2b_kg_m2.*(1+ew2b_osw).*ew2b_w_l.*C2_
MJ_KG;
    if T_EW == 3

specew3bnum(1:2:ew3b,j)=ew3b_rep.*ew3b_kg_m2.*(1+ew3b_osw).*ew3b_w_l.*C2_
KGCO2_KG;

specew3bnum(2:2:ew3b,j)=ew3b_rep.*ew3b_kg_m2.*(1+ew3b_osw).*ew3b_w_l.*C2_
MJ_KG;
```

```
        end
end

if B_T ~= 4

specpwbnum(1:2:pwb,j)=pwb_rep.*pwb_kg_m2.*(1+pwb_osw).*pwb_w_l.*C2_KGCO2_
KG;

specpwbnum(2:2:pwb,j)=pwb_rep.*pwb_kg_m2.*(1+pwb_osw).*pwb_w_l.*C2_MJ_KG;
    if B_T == 5

specpw2bnum(1:2:pw2b,j)=pw2b_rep.*pw2b_kg_m2.*(1+pw2b_osw).*pw2b_w_l.*C2_
KGCO2_KG;

specpw2bnum(2:2:pw2b,j)=pw2b_rep.*pw2b_kg_m2.*(1+pw2b_osw).*pw2b_w_l.*C2_
MJ_KG;
    end
end
end
```

Importing B6 if existing:

```
for j=18 % 12
specfobnum(1:fob,j)=0;
specgfbnum(1:gfb,j)=0;
specewbnum(1:ewb,j)=0;
speciwbnum(1:iwb,j)=0;
specufbnum(1:ufb,j)=0;
specroofbnum(1:rb,j)=0;
specwinbnum(1:wb,j)=0;
specindbnum(1:edob,j)=0;
specindbnum(1:idob,j)=0;

if T_EW ~= 1 % to get other building elements data
    specew2bnum(1:ew2b,j)=0;
    if T_EW == 3
        specew3bnum(1:ew3b,j)=0;
    end
end

if B_T ~= 4
    specpwbnum(1:pwb,j)=0;
    if B_T == 5
        specpw2bnum(1:pw2b,j)=0;
    end
end
end
```

Calcualtion of C1-C4 Mmodule: End of Use

C1: Demolition energy anc CO2 emissions

```
% 2010-Life Cycle primary energy used and carbon emissions of 8-storey
building
% demolition:
% CONSTRUCTION:
% EE=80kWh/m2 = 288MJ/m2
% EC=27KgCO2e/m2
% DEMOLITION:
% EE=10 kWh/m2 = 36 MJ/m2
% EC=3 KgCO2e/m2


% 2012-LCA of the demolition of a school building:
% DEMOLITION:
% 37 MJ/m2 == 0,526 MJ/Kg
% Assuming 2,67KgCO2e/L of fuel we have 8400 L of fuel used. Hence:
% EC=2,49 KgCO2e/m2 == 0,00164 KgCO2e/Kg


% for this thesis figures are the following:
DEM_EE_m2 = 36; % MJ/m2
DEM_EC_m2 = 3.4; % KgCO2e/m2


% this is blocked by now until back to complete building assessment:
% BASE_DEM_EE = DEM_EE_m2*B_GIFA;
% BASE_DEM_EC = DEM_EC_m2*B_GIFA;
```

FOR VALIDATION: using demolition figures from kellemberger for carmen galan paper

this is the figures that carmen's paper uses. But no for simulating BRE or YOKER.

```
DEM_EE_MJ_m3 = MJ_M3_num (3,1); % MJ/m3 of material used. C.Galan paper
uses this number
DEM_EE_MJ_m3_diesel = MJ_M3_num (3,1)*0.7; % MJ/m3
DEM_EE_MJ_m3_elect = MJ_M3_num (3,1)*0.3; % MJ/m3
DEM_EE_KWH_m3_elect = DEM_EE_MJ_m3_elect/3.6; % MJ/m3

DEM_EC_KGCO2e_m3_diesel = 23.3111;
DEM_EC_KGCO2e_m3_elect = 15.41;
DEM_EC_KGCO2e_m3 = DEM_EC_KGCO2e_m3_diesel + DEM_EC_KGCO2e_m3_elect;

DEM_CED_MJ_m3_diesel = 357.42;
DEM_CED_MJ_m3_elect = 336.08;
DEM_CED_MJ_m3 = DEM_CED_MJ_m3_diesel + DEM_CED_MJ_m3_elect;

BASE_DEM_EE = DEM_CED_MJ_m3*EW_m3_total;
BASE_DEM_EC = DEM_EC_KGCO2e_m3*EW_m3_total;
```

GETTING THE CALCULATION TO EXCEL:

```
for j=19 % 13
specfobnum(1:fob,j)=0;
specgfbnum(1:gfb,j)=0;
specewbnum(1:ewb,j)=0;
```

```
speciwbnum(1:iwb,j)=0;
specufbnum(1:ufb,j)=0;
specroofbnum(1:rb,j)=0;
specwinbnum(1:wb,j)=0;
specexdbnum(1:edob,j)=0;
specindbnum(1:idob,j)=0;

if T_EW ~= 1 % to get other building elements data
    specew2bnum(1:ew2b,j)=0;
    if T_EW == 3
        specew3bnum(1:ew3b,j)=0;
    end
end

if B_T ~= 4
    specpwbnum(1:pwb,j)=0;
    if B_T == 5
        specpw2bnum(1:pw2b,j)=0;
    end
end
end
```

C2: Transport "Site to Final Disposal"

```
% FOR CARMEN'S PAPER ASSESSMENTS: same but without the % of waste sent to
% landfill.
for j=20 % 14
specfobnum(1:2:fob,j)=fob_kg_m2.*C2_KGCO2_KG;
specfobnum(2:2:fob,j)=fob_kg_m2.*C2_MJ_KG;

specgfbnum(1:2:gfb,j)=gfb_kg_m2.*C2_KGCO2_KG;
specgfbnum(2:2:gfb,j)=gfb_kg_m2.*C2_MJ_KG;

specewbnum(1:2:ewb,j)=ewb_kg_m2.*C2_KGCO2_KG;
specewbnum(2:2:ewb,j)=ewb_kg_m2.*C2_MJ_KG;

speciwbnum(1:2:iwb,j)=iwb_kg_m2.*C2_KGCO2_KG;
speciwbnum(2:2:iwb,j)=iwb_kg_m2.*C2_MJ_KG;

specufbnum(1:2:ufb,j)=ufb_kg_m2.*C2_KGCO2_KG;
specufbnum(2:2:ufb,j)=ufb_kg_m2.*C2_MJ_KG;

specroofbnum(1:2:rb,j)=rb_kg_m2.*C2_KGCO2_KG;
specroofbnum(2:2:rb,j)=rb_kg_m2.*C2_MJ_KG;

specwinbnum(1:2:wb,j)=wb_kg_m2.*C2_KGCO2_KG;
specwinbnum(2:2:wb,j)=wb_kg_m2.*C2_MJ_KG;

specexdbnum(1:2:edob,j)=edob_kg_m2.*C2_KGCO2_KG;
specexdbnum(2:2:edob,j)=edob_kg_m2.*C2_MJ_KG;
```

```
specindbnum(1:2:idob,j)=idob_kg_m2.*C2_KGCO2_KG;
specindbnum(2:2:idob,j)=idob_kg_m2.*C2_MJ_KG;

if T_EW ~= 1 % to get other building elements data
    specew2bnum(1:2:ew2b,j)=ew2b_kg_m2.*C2_KGCO2_KG;
    specew2bnum(2:2:ew2b,j)=ew2b_kg_m2.*C2_MJ_KG;
    if T_EW == 3
        specew3bnum(1:2:ew3b,j)=ew3b_kg_m2.*C2_KGCO2_KG;
        specew3bnum(2:2:ew3b,j)=ew3b_kg_m2.*C2_MJ_KG;
    end
end

if B_T ~= 4
    specpwbnum(1:2:pwb,j)=pwb_kg_m2.*C2_KGCO2_KG;
    specpwbnum(2:2:pwb,j)=pwb_kg_m2.*C2_MJ_KG;
    if B_T == 5
        specpw2bnum(1:2:pw2b,j)=pw2b_kg_m2.*C2_KGCO2_KG;
        specpw2bnum(2:2:pw2b,j)=pw2b_kg_m2.*C2_MJ_KG;
    end
end
end
```

C3: Waste Processing impact

Assuming that separation is taken place on site by man force.

```
for j=21 % 15
specfobnum(1:fob,j)=0;
specgfbnum(1:gfb,j)=0;
specewbnum(1:ewb,j)=0;
speciwbnum(1:iwb,j)=0;
specufbnum(1:ufb,j)=0;
specroofbnum(1:rb,j)=0;
specwinbnum(1:wb,j)=0;
specexdbnum(1:edob,j)=0;
specindbnum(1:idob,j)=0;

if T_EW ~= 1 % to get other building elements data
    specew2bnum(1:ew2b,j)=0;
    if T_EW == 3
        specew3bnum(1:ew3b,j)=0;
    end
end

if B_T ~= 4
    specpwbnum(1:pwb,j)=0;
    if B_T == 5
        specpw2bnum(1:pw2b,j)=0;
    end
end
```

```
end
```

C4: Final Disposal impact

Calculating Disposal Loads for Module "C4: Final Disposal"

Taking information from "2016-An Agent based environmental impact

Assessment of building demolition waste management" (Tw= tonne of material landfilled moved) (Kgw= kilogram of material landfilled moved) (Tf= tonne of fuel oil) (Kgf= kilogram of fuel oil) Fuel oil figure: 0.857Kgf / Tw == 0.000857 Kgf/Kgw (I)

```
DISP_rate = 0.000857; % Kgf/Kgw.

% Fuel properties and conversion factors taken from DEFRA UK GOV EXCEL
TABLE(2016):
% Fuel Density*: 0,832 Kgf/L (II)

% ENERGY:
% Fuel MJ per L rate:  35.99 MJ/L (III)
% (III)/(II) = MJ/Kgf (IV)
DISP_MJ_kgf = 43.149; % MJ/Kgf
% (IV)*(I) = MJ/Kgw (V)
C4_FUEL_MJ_Kgm = DISP_MJ_kgf*DISP_rate;
% C4_FUEL_MJ_Kgm = 0,036978;

% GWP:
% Fuel KgCO2e per L rate:  2.67 KgCO2e/L (VI)
% (VI)/(II) = KgCO2e/Kgf (VII)
DISP_Kgco2e_kgf = 3.2091; % KgCO2e/Kgf
% (VII)*(I) = KgCO2e/Kgw (VIII)
C4_FUEL_KgCO2e_Kgm = DISP_Kgco2e_kgf*DISP_rate;
% C4_FUEL_KgCO2e_Kgm = 0.002763; % (VI)DIrect figure

% %% Taking info from
% % ***THIS IS FOR THESIS ONLY***
%
% % "2006-MODELLING OF ENVIRONMENTAL IMPACTS OF SOLID WASTE
% % LANDFILLING WITHIN THE LIFE CYCLE ANALYSIS PROGRAM EASEWASTE - TABLE
1".
%
% % First we calculate impact from diesel consumption:
% % From transport we have figures for MJ and KgCO2e per Litre of fuel:
% % C4_FUEL_MJ_L = 35.998;
% % C4_FUEL_KgCO2e_L = 2.67;
% % C4_FUEL_L_ton = 1.1;
%
% % Second we calculate figures from soil consumption:
% C4_SOIL_Kgs_Kgm = 0.5;
% C4_SOIL_MJ_Kgs = 0.45;
% C4_SOIL_KgCO2e_Kgs = 0.024;
%
```

```
% C4_SOIL_MJ_Kgm = C4_SOIL_MJ_Kgs*C4_SOIL_Kgs_Kgm; % = 0,225
% C4_SOIL_KgCO2e_Kgm = C4_SOIL_KgCO2e_Kgs*C4_SOIL_Kgs_Kgm; % = 0,012
%
% % % and now we sum both figures ***FOR THESIS****:
% C4_KgCO2e_Kgm = C4_FUEL_KgCO2e_Kgm+C4_SOIL_KgCO2e_Kgm;
% C4_MJ_Kgm = C4_FUEL_MJ_Kgm+C4_SOIL_MJ_Kgm;
%
% % and now we sum both figures FOR CARMEN'S PAPER:
% % C4_KgCO2e_Kgm = 0.01;
% % C4_MJ_Kgm = C4_SOIL_MJ_Kgm;
%
% C4_B_MJ = C4_MJ_Kgm*EW_kg_total;
% C4_B_KgCO2e = C4_KgCO2e_Kgm*EW_kg_total;
```

USING FIGURES FOR CARMEN'S PAPER:

```
C4_KgCO2e_Kgm = 0.0128;
C4_MJ_Kgm = 0.3329;


% if P_NAME (6) == 'R'
%     C4_KgCO2e_Kgm = C4_KgCO2e_Kgm*1.0742;
%     C4_MJ_Kgm = C4_MJ_Kgm*1.0742;
% end
```

PASSING THE CALCULATIONS TO EXCEL SPREADCHEET:

```
for j=22 % 16
specfobnum(1:2:fob,j)=fob_kg_m2.*C4_KgCO2e_Kgm;
specfobnum(2:2:fob,j)=fob_kg_m2.*C4_MJ_Kgm;

specgfbnum(1:2:gfb,j)=gfb_kg_m2.*C4_KgCO2e_Kgm;
specgfbnum(2:2:gfb,j)=gfb_kg_m2.*C4_MJ_Kgm;

specewbnum(1:2:ewb,j)=ewb_kg_m2.*C4_KgCO2e_Kgm;
specewbnum(2:2:ewb,j)=ewb_kg_m2.*C4_MJ_Kgm;

speciwbnum(1:2:iwb,j)=iwb_kg_m2.*C4_KgCO2e_Kgm;
speciwbnum(2:2:iwb,j)=iwb_kg_m2.*C4_MJ_Kgm;

specufbnum(1:2:ufb,j)=ufb_kg_m2.*C4_KgCO2e_Kgm;
specufbnum(2:2:ufb,j)=ufb_kg_m2.*C4_MJ_Kgm;

specroofbnum(1:2:rb,j)=rb_kg_m2.*C4_KgCO2e_Kgm;
specroofbnum(2:2:rb,j)=rb_kg_m2.*C4_MJ_Kgm;

specwinbnum(1:2:wb,j)=wb_kg_m2.*C4_KgCO2e_Kgm;
specwinbnum(2:2:wb,j)=wb_kg_m2.*C4_MJ_Kgm;

specexdbnum(1:2:edob,j)=edob_kg_m2.*C4_KgCO2e_Kgm;
specexdbnum(2:2:edob,j)=edob_kg_m2.*C4_MJ_Kgm;
```

```
specindbnum(1:2:idob,j)=idob_kg_m2.*C4_KgCO2e_Kgm;
specindbnum(2:2:idob,j)=idob_kg_m2.*C4_MJ_Kgm;

if T_EW ~= 1 % to get other building elements data
    specew2bnum(1:2:ew2b,j)=ew2b_kg_m2.*C4_KgCO2e_Kgm;
    specew2bnum(2:2:ew2b,j)=ew2b_kg_m2.*C4_MJ_Kgm;
    if T_EW == 3
        specew3bnum(1:2:ew3b,j)=ew3b_kg_m2.*C4_KgCO2e_Kgm;
        specew3bnum(2:2:ew3b,j)=ew3b_kg_m2.*C4_MJ_Kgm;
    end
end

if B_T ~= 4
    specpwbnum(1:2:pwb,j)=pwb_kg_m2.*C4_KgCO2e_Kgm;
    specpwbnum(2:2:pwb,j)=pwb_kg_m2.*C4_MJ_Kgm;
    if B_T == 5
        specpw2bnum(1:2:pw2b,j)=pw2b_kg_m2.*C4_KgCO2e_Kgm;
        specpw2bnum(2:2:pw2b,j)=pw2b_kg_m2.*C4_MJ_Kgm;
    end
end
end
```

Adding all impact in stage A:

Total impact for A-MANUFACTURING STAGE

```
for j=23
specfobnum(1:fob,j)=0;
specgfbnum(1:gfb,j)=0;
specewbnum(1:ewb,j)=0;
speciwbnum(1:iwb,j)=0;
specufbnum(1:ufb,j)=0;
specroofbnum(1:rb,j)=0;
specwinbnum(1:wb,j)=0;
specexdbnum(1:edob,j)=0;
specindbnum(1:idob,j)=0;

if T_EW ~= 1 % to get other building elements data
    specew2bnum(1:ew2b,j)=0;
    if T_EW == 3
        specew3bnum(1:ew3b,j)=0;
    end
end

if B_T ~= 4
    specpwbnum(1:pwb,j)=0;
    if B_T == 5
        specpw2bnum(1:pw2b,j)=0;
    end
end
end
```

```
end
% Adding all impacts related to A Stage:
for j=7:13
    for i=23
specfobnum(1:fob,i)=specfobnum(1:fob,i)+specfobnum(1:fob,j);
specgfbnum(1:gfb,i)=specgfbnum(1:gfb,i)+specgfbnum(1:gfb,j);
specewbnum(1:ewb,i)=specewbnum(1:ewb,i)+specewbnum(1:ewb,j);
speciwbnum(1:iwb,i)=speciwbnum(1:iwb,i)+speciwbnum(1:iwb,j);
specufbnum(1:ufb,i)=specufbnum(1:ufb,i)+specufbnum(1:ufb,j);
specroofbnum(1:rb,i)=specroofbnum(1:rb,i)+specroofbnum(1:rb,j);
specwinbnum(1:wb,i)=specwinbnum(1:wb,i)+specwinbnum(1:wb,j);
specexdbnum(1:edob,i)=specexdbnum(1:edob,i)+specexdbnum(1:edob,j);
specindbnum(1:idob,i)=specindbnum(1:idob,i)+specindbnum(1:idob,j);

if T_EW ~= 1 % to get other building elements data
    specew2bnum(1:ew2b,i)=specew2bnum(1:ew2b,i)+specew2bnum(1:ew2b,j);
    if T_EW == 3

specew3bnum(1:ew3b,i)=specew3bnum(1:ew3b,i)+specew3bnum(1:ew3b,j);
    end
end

if B_T ~= 4
    specpwbnum(1:pwb,i)=specpwbnum(1:pwb,i)+specpwbnum(1:pwb,j);
    if B_T == 5

specpw2bnum(1:pw2b,i)=specpw2bnum(1:pw2b,i)+specpw2bnum(1:pw2b,j);
    end
end
    end
end

for j=23
specfobnum(1:fob,j)=specfobnum(1:fob,j)-specfobnum(1:fob,11);
specgfbnum(1:gfb,j)=specgfbnum(1:gfb,j)-specgfbnum(1:gfb,11);
specewbnum(1:ewb,j)=specewbnum(1:ewb,j)-specewbnum(1:ewb,11);
speciwbnum(1:iwb,j)=speciwbnum(1:iwb,j)-speciwbnum(1:iwb,11);
specufbnum(1:ufb,j)=specufbnum(1:ufb,j)-specufbnum(1:ufb,11);
specroofbnum(1:rb,j)=specroofbnum(1:rb,j)-specroofbnum(1:rb,11);
specwinbnum(1:wb,j)=specwinbnum(1:wb,j)-specwinbnum(1:wb,11);
specexdbnum(1:edob,j)=specexdbnum(1:edob,j)-specexdbnum(1:edob,11);
specindbnum(1:idob,j)=specindbnum(1:idob,j)-specindbnum(1:idob,11);

if T_EW ~= 1 % to get other building elements data
    specew2bnum(1:ew2b,j)=specew2bnum(1:ew2b,j)-specew2bnum(1:ew2b,11);
    if T_EW == 3
        specew3bnum(1:ew3b,j)=specew3bnum(1:ew3b,j)-
specew3bnum(1:ew3b,11);
    end
end
```

```
if B_T ~= 4
    specpwbnum(1:pwb,j)=specpwbnum(1:pwb,j)-specpwbnum(1:pwb,11);
    if B_T == 5
        specpw2bnum(1:pw2b,j)=specpw2bnum(1:pw2b,j)-
specpw2bnum(1:pw2b,11);
    end
end
end
```

Adding all impact in sub-stage B4: REPLACEMENTS

Making a column oz zeros

```
for j=24
specfobnum(1:fob,j)=0;
specgfbnum(1:gfb,j)=0;
specewbnum(1:ewb,j)=0;
speciwbnum(1:iwb,j)=0;
specufbnum(1:ufb,j)=0;
specroofbnum(1:rb,j)=0;
specwinbnum(1:wb,j)=0;
specexdbnum(1:edob,j)=0;
specindbnum(1:idob,j)=0;

if T_EW ~= 1 % to get other building elements data
    specew2bnum(1:ew2b,j)=0;
    if T_EW == 3
        specew3bnum(1:ew3b,j)=0;
    end
end

if B_T ~= 4
    specpwbnum(1:pwb,j)=0;
    if B_T == 5
        specpw2bnum(1:pw2b,j)=0;
    end
end
end

% Suming all substages:
for j=14:18
    for i=24
specfobnum(1:fob,i)=specfobnum(1:fob,i)+specfobnum(1:fob,j);
specgfbnum(1:gfb,i)=specgfbnum(1:gfb,i)+specgfbnum(1:gfb,j);
specewbnum(1:ewb,i)=specewbnum(1:ewb,i)+specewbnum(1:ewb,j);
speciwbnum(1:iwb,i)=speciwbnum(1:iwb,i)+speciwbnum(1:iwb,j);
specufbnum(1:ufb,i)=specufbnum(1:ufb,i)+specufbnum(1:ufb,j);
specroofbnum(1:rb,i)=specroofbnum(1:rb,i)+specroofbnum(1:rb,j);
specwinbnum(1:wb,i)=specwinbnum(1:wb,i)+specwinbnum(1:wb,j);
```

374

```
specexdbnum(1:edob,i)=specexdbnum(1:edob,i)+specexdbnum(1:edob,j);
specindbnum(1:idob,i)=specindbnum(1:idob,i)+specindbnum(1:idob,j);

if T_EW ~= 1 % to get other building elements data
    specew2bnum(1:ew2b,i)=specew2bnum(1:ew2b,i)+specew2bnum(1:ew2b,j);
    if T_EW == 3

specew3bnum(1:ew3b,i)=specew3bnum(1:ew3b,i)+specew3bnum(1:ew3b,j);
    end
end

if B_T ~= 4
    specpwbnum(1:pwb,i)=specpwbnum(1:pwb,i)+specpwbnum(1:pwb,j);
    if B_T == 5

specpw2bnum(1:pw2b,i)=specpw2bnum(1:pw2b,i)+specpw2bnum(1:pw2b,j);
    end
end
    end
end

for j=24
specfobnum(1:fob,j)=specfobnum(1:fob,j)-specfobnum(1:fob,15);
specgfbnum(1:gfb,j)=specgfbnum(1:gfb,j)-specgfbnum(1:gfb,15);
specgfbnum(1:gfb,j)=specgfbnum(1:gfb,j)-specgfbnum(1:gfb,15);
specewbnum(1:ewb,j)=specewbnum(1:ewb,j)-specewbnum(1:ewb,15);
speciwbnum(1:iwb,j)=speciwbnum(1:iwb,j)-speciwbnum(1:iwb,15);
specufbnum(1:ufb,j)=specufbnum(1:ufb,j)-specufbnum(1:ufb,15);
specroofbnum(1:rb,j)=specroofbnum(1:rb,j)-specroofbnum(1:rb,15);
specwinbnum(1:wb,j)=specwinbnum(1:wb,j)-specwinbnum(1:wb,15);
specexdbnum(1:edob,j)=specexdbnum(1:edob,j)-specexdbnum(1:edob,15);
specindbnum(1:idob,j)=specindbnum(1:idob,j)-specindbnum(1:idob,15);

if T_EW ~= 1 % to get other building elements data
    specew2bnum(1:ew2b,j)=specew2bnum(1:ew2b,j)-specew2bnum(1:ew2b,15);
    if T_EW == 3
        specew3bnum(1:ew3b,j)=specew3bnum(1:ew3b,j)-
specew3bnum(1:ew3b,15);
    end
end

if B_T ~= 4
    specpwbnum(1:pwb,j)=specpwbnum(1:pwb,j)-specpwbnum(1:pwb,15);
    if B_T == 5
        specpw2bnum(1:pw2b,j)=specpw2bnum(1:pw2b,j)-
specpw2bnum(1:pw2b,15);
    end
end
end
```

Adding all impact in Stage C: END-OF-LIFE

```
for j=25
specfobnum(1:fob,j)=0;
specgfbnum(1:gfb,j)=0;
specewbnum(1:ewb,j)=0;
speciwbnum(1:iwb,j)=0;
specufbnum(1:ufb,j)=0;
specroofbnum(1:rb,j)=0;
specwinbnum(1:wb,j)=0;
specexdbnum(1:edob,j)=0;
specindbnum(1:idob,j)=0;

if T_EW ~= 1 % to get other building elements data
    specew2bnum(1:ew2b,j)=0;
    if T_EW == 3
        specew3bnum(1:ew3b,j)=0;
    end
end

if B_T ~= 4
    specpwbnum(1:pwb,j)=0;
    if B_T == 5
        specpw2bnum(1:pw2b,j)=0;
    end
end
end
% Suming all Substages:
for j=19:22
    for i=25
specfobnum(1:fob,i)=specfobnum(1:fob,i)+specfobnum(1:fob,j);
specgfbnum(1:gfb,i)=specgfbnum(1:gfb,i)+specgfbnum(1:gfb,j);
specewbnum(1:ewb,i)=specewbnum(1:ewb,i)+specewbnum(1:ewb,j);
speciwbnum(1:iwb,i)=speciwbnum(1:iwb,i)+speciwbnum(1:iwb,j);
specufbnum(1:ufb,i)=specufbnum(1:ufb,i)+specufbnum(1:ufb,j);
specroofbnum(1:rb,i)=specroofbnum(1:rb,i)+specroofbnum(1:rb,j);
specwinbnum(1:wb,i)=specwinbnum(1:wb,i)+specwinbnum(1:wb,j);
specexdbnum(1:edob,i)=specexdbnum(1:edob,i)+specexdbnum(1:edob,j);
specindbnum(1:idob,i)=specindbnum(1:idob,i)+specindbnum(1:idob,j);

if T_EW ~= 1 % to get other building elements data
    specew2bnum(1:ew2b,i)=specew2bnum(1:ew2b,i)+specew2bnum(1:ew2b,j);
    if T_EW == 3

specew3bnum(1:ew3b,i)=specew3bnum(1:ew3b,i)+specew3bnum(1:ew3b,j);
    end
end

if B_T ~= 4
    specpwbnum(1:pwb,i)=specpwbnum(1:pwb,i)+specpwbnum(1:pwb,j);
```

```
    if B_T == 5

specpw2bnum(1:pw2b,i)=specpw2bnum(1:pw2b,i)+specpw2bnum(1:pw2b,j);
    end
end
    end
end
```

Generating a Total by BE (all stages):

```
for j=26
specfobnum(1:fob,j)=0;
specgfbnum(1:gfb,j)=0;
specewbnum(1:ewb,j)=0;
speciwbnum(1:iwb,j)=0;
specufbnum(1:ufb,j)=0;
specroofbnum(1:rb,j)=0;
specwinbnum(1:wb,j)=0;
specexdbnum(1:edob,j)=0;
specindbnum(1:idob,j)=0;

if T_EW ~= 1 % to get other building elements data
    specew2bnum(1:ew2b,j)=0;
    if T_EW == 3
        specew3bnum(1:ew3b,j)=0;
    end
end

if B_T ~= 4
    specpwbnum(1:pwb,j)=0;
    if B_T == 5
        specpw2bnum(1:pw2b,j)=0;
    end
end
end
% Suming all Stages:
for j=23:25
    for i=26
specfobnum(1:fob,i)=specfobnum(1:fob,i)+specfobnum(1:fob,j);
specgfbnum(1:gfb,i)=specgfbnum(1:gfb,i)+specgfbnum(1:gfb,j);
specewbnum(1:ewb,i)=specewbnum(1:ewb,i)+specewbnum(1:ewb,j);
speciwbnum(1:iwb,i)=speciwbnum(1:iwb,i)+speciwbnum(1:iwb,j);
specufbnum(1:ufb,i)=specufbnum(1:ufb,i)+specufbnum(1:ufb,j);
specroofbnum(1:rb,i)=specroofbnum(1:rb,i)+specroofbnum(1:rb,j);
specwinbnum(1:wb,i)=specwinbnum(1:wb,i)+specwinbnum(1:wb,j);
specexdbnum(1:edob,i)=specexdbnum(1:edob,i)+specexdbnum(1:edob,j);
specindbnum(1:idob,i)=specindbnum(1:idob,i)+specindbnum(1:idob,j);

if T_EW ~= 1 % to get other building elements data
    specew2bnum(1:ew2b,i)=specew2bnum(1:ew2b,i)+specew2bnum(1:ew2b,j);
```

```matlab
    if T_EW == 3

specew3bnum(1:ew3b,i)=specew3bnum(1:ew3b,i)+specew3bnum(1:ew3b,j);
    end
end

if B_T ~= 4
    specpwbnum(1:pwb,i)=specpwbnum(1:pwb,i)+specpwbnum(1:pwb,j);
    if B_T == 5

specpw2bnum(1:pw2b,i)=specpw2bnum(1:pw2b,i)+specpw2bnum(1:pw2b,j);
    end
end
    end
end
```

Generating a Total by stage & Building element (all materials involved in that building element):

```matlab
for j=7:26

specfobnum(fob+1:fob+2,j)=[sum(specfobnum(1:2:fob,j));sum(specfobnum(2:2:
fob,j))];

specgfbnum(gfb+1:gfb+2,j)=[sum(specgfbnum(1:2:gfb,j));sum(specgfbnum(2:2:
gfb,j))];

specewbnum(ewb+1:ewb+2,j)=[sum(specewbnum(1:2:ewb,j));sum(specewbnum(2:2:
ewb,j))];

speciwbnum(iwb+1:iwb+2,j)=[sum(speciwbnum(1:2:iwb,j));sum(speciwbnum(2:2:
iwb,j))];

specufbnum(ufb+1:ufb+2,j)=[sum(specufbnum(1:2:ufb,j));sum(specufbnum(2:2:
ufb,j))];

specroofbnum(rb+1:rb+2,j)=[sum(specroofbnum(1:2:rb,j));sum(specroofbnum(2
:2:rb,j))];

specwinbnum(wb+1:wb+2,j)=[sum(specwinbnum(1:2:wb,j));sum(specwinbnum(2:2:
wb,j))];

specexdbnum(edob+1:edob+2,j)=[sum(specexdbnum(1:2:edob,j));sum(specexdbnu
m(2:2:edob,j))];

specindbnum(idob+1:idob+2,j)=[sum(specindbnum(1:2:idob,j));sum(specindbnu
m(2:2:idob,j))];

    if T_EW ~= 1 % to get other building elements data
```

```
specew2bnum(ew2b+1:ew2b+2,j)=[sum(specew2bnum(1:2:ew2b,j));sum(specew2bnu
m(2:2:ew2b,j))];
        if T_EW == 3

specew3bnum(ew3b+1:ew3b+2,j)=[sum(specew3bnum(1:2:ew3b,j));sum(specew3bnu
m(2:2:ew3b,j))];
        end
    end

    if B_T ~= 4

specpwbnum(pwb+1:pwb+2,j)=[sum(specpwbnum(1:2:pwb,j));sum(specpwbnum(2:2:
pwb,j))];
        if B_T == 5

specpw2bnum(pw2b+1:pw2b+2,j)=[sum(specpw2bnum(1:2:pw2b,j));sum(specpw2bnu
m(2:2:pw2b,j))];
        end
    end
end
```

Writing the excel with all data

```
for j=26
    %for windows:
% xlswrite(ProjectSPECbase,specfobnum(1:fob,3:6),'FOUNDATIONS','F4');
% xlswrite(ProjectSPECbase,specfobnum(1:fob+2,7:j),'FOUNDATIONS','J4');

% xlswrite(ProjectSPECbase,specgfbnum(1:gfb,3:6),'GROUND_FLOORS','F4');
% xlswrite(ProjectSPECbase,specgfbnum(1:gfb+2,7:j),'GROUND_FLOORS','J4');

% xlswrite(ProjectSPECbase,specewbnum(1:ewb,3:6),'EXT_WALLS','F4');
% xlswrite(ProjectSPECbase,specewbnum(1:ewb+2,7:j),'EXT_WALLS','J4');

% xlswrite(ProjectSPECbase,speciwbnum(1:iwb,3:6),'INT_WALLS','F4');
% xlswrite(ProjectSPECbase,speciwbnum(1:iwb+2,7:j),'INT_WALLS','J4');

% xlswrite(ProjectSPECbase,specpwbnum(1:pwb,3:6),'PAR_WALLS','F4');
% xlswrite(ProjectSPECbase,specpwbnum(1:pwb+2,7:j),'PAR_WALLS','J4');

% xlswrite(ProjectSPECbase,specufbnum(1:ufb,3:6),'UPPER_FLOORS','F4');
% xlswrite(ProjectSPECbase,specufbnum(1:ufb+2,7:j),'UPPER_FLOORS','J4');

% xlswrite(ProjectSPECbase,specroofbnum(1:rb,3:6),'ROOF','F4');
% xlswrite(ProjectSPECbase,specroofbnum(1:rb+2,7:j),'ROOF','J4');

% xlswrite(ProjectSPECbase,specwinbnum(1:wb,3:6),'WINDOWS','F4');
% xlswrite(ProjectSPECbase,specwinbnum(1:wb+2,7:j),'WINDOWS','J4');
```

```
% xlswrite(ProjectSPECbase,specexdbnum(1:edob,3:6),'EXT_DOORS','F4');
% xlswrite(ProjectSPECbase,specexdbnum(1:edob+2,7:j),'EXT_DOORS','J4');

% xlswrite(ProjectSPECbase,specindbnum(1:idob,3:6),'INT_DOORS','F4');
% xlswrite(ProjectSPECbase,specindbnum(1:idob+2,7:j),'INT_DOORS','J4');

% for mac:
writematrix(specfobnum(1:fob,3:6),ProjectSPECbase,'sheet','FOUNDATIONS','
range','F4');
writematrix(specfobnum(1:fob+2,7:j),ProjectSPECbase,'sheet','FOUNDATIONS'
,'range','J4');

writematrix(specgfbnum(1:gfb,3:6),ProjectSPECbase,'sheet','GROUND_FLOORS'
,'range','F4');
writematrix(specgfbnum(1:gfb+2,7:j),ProjectSPECbase,'sheet','GROUND_FLOOR
S','range','J4');

writematrix(specewbnum(1:ewb,3:6),ProjectSPECbase,'sheet','EXT_WALLS-
1','range','F4');
writematrix(specewbnum(1:ewb+2,7:j),ProjectSPECbase,'sheet','EXT_WALLS-
1','range','J4');

writematrix(speciwbnum(1:iwb,3:6),ProjectSPECbase,'sheet','INT_WALLS','ra
nge','F4');
writematrix(speciwbnum(1:iwb+2,7:j),ProjectSPECbase,'sheet','INT_WALLS','
range','J4');

writematrix(specufbnum(1:ufb,3:6),ProjectSPECbase,'sheet','UPPER_FLOORS',
'range','F4');
writematrix(specufbnum(1:ufb+2,7:j),ProjectSPECbase,'sheet','UPPER_FLOORS
','range','J4');

writematrix(specroofbnum(1:rb,3:6),ProjectSPECbase,'sheet','ROOF','range'
,'F4');
writematrix(specroofbnum(1:rb+2,7:j),ProjectSPECbase,'sheet','ROOF','rang
e','J4');

writematrix(specwinbnum(1:wb,3:6),ProjectSPECbase,'sheet','WINDOWS','rang
e','F4');
writematrix(specwinbnum(1:wb+2,7:j),ProjectSPECbase,'sheet','WINDOWS','ra
nge','J4');

writematrix(specexdbnum(1:edob,3:6),ProjectSPECbase,'sheet','EXT_DOORS','
range','F4');
writematrix(specexdbnum(1:edob+2,7:j),ProjectSPECbase,'sheet','EXT_DOORS'
,'range','J4');

writematrix(specindbnum(1:idob,3:6),ProjectSPECbase,'sheet','INT_DOORS','
range','F4');
```

```matlab
writematrix(specindbnum(1:idob+2,7:j),ProjectSPECbase,'sheet','INT_DOORS'
,'range','J4');

if T_EW ~= 1 % to get other building elements data

writematrix(specew2bnum(1:ew2b,3:6),ProjectSPECbase,'sheet','EXT_WALLS-
2','range','F4');

writematrix(specew2bnum(1:ew2b+2,7:j),ProjectSPECbase,'sheet','EXT_WALLS-
2','range','J4');
    if T_EW == 3

writematrix(specew3bnum(1:ew3b,3:6),ProjectSPECbase,'sheet','EXT_WALLS-
3','range','F4');

writematrix(specew3bnum(1:ew3b+2,7:j),ProjectSPECbase,'sheet','EXT_WALLS-
3','range','J4');
    end
end

if B_T ~= 4
    writematrix(specpwbnum(1:pwb,3:6),ProjectSPECbase,'sheet','PAR_WALLS-
1','range','F4');

writematrix(specpwbnum(1:pwb+2,7:j),ProjectSPECbase,'sheet','PAR_WALLS-
1','range','J4');
    if B_T == 5

writematrix(specpw2bnum(1:pw2b,3:6),ProjectSPECbase,'sheet','PAR_WALLS-
2','range','F4');

writematrix(specpw2bnum(1:pw2b+2,7:j),ProjectSPECbase,'sheet','PAR_WALLS-
2','range','J4');
    end
end
end
```

(5) Reporting numerical and graphical results

GRAPHICS RESULTS AND COMPARISON EXCEL FILES

```
formatOut = 'yyyy_mm_dd';
DATE=datestr(date,formatOut);
FILE_RESULTS_NAME = strcat(P_NAME,'_',SCENARIO,'_RESULTS_',DATE,'.mat');
```

Defining the name of the project and scenario assessed:

```
clc;
disp ' ';
disp ' ';
fprintf ('Just a reminder, the LCA performed is the
%s_SCENARIO_%s',P_NAME,SCENARIO);
disp ' ';
disp ' ';


% RESULTS FOR EXTERNAL WALLS
R_indicator_E={'A','B','C'};
R_indicator_E_pie={'A: ';'B: ';'C: '};
R_indicator_E_TOTAL={'A','B','C','TOTAL'};

% SUBSTAGES SUBDIVIDED with B6: IN-USE impact
R_indicator_EE_SI_B6={'A1-A3','A4','A5-a','A5-b','A5-c','A5-d','A5-
e','B4-a','B4-b','B4-c','B4-d','B6','C1','C2','C3','C4'};
% SUBSTAGES SUBDIVIDED without B6:
R_indicator_EE_NO_B6={'A1-A3','A4','A5-a','A5-b','A5-c','A5-d','A5-
e','B4-a','B4-b','B4-c','B4-d','C1','C2','C3','C4'};
% SUBSTAGES with B6:
R_indicator_EE_SUBSTAGES_SI_B6={'A1-
A3','A4','A5','B4','B6','C1','C2','C3','C4'};
R_indicator_EE_SUBSTAGES_SI_B6_pie={'A1-A3: ';'A4: ';'A5: ';'B4: ';'B6:
';'C1: ';'C2: ';'C3: ';'C4: '};
% SUBSTAGES without B6:
R_indicator_EE_SUBSTAGES_NO_B6={'A1-
A3','A4','A5','B4','C1','C2','C3','C4'};
R_indicator_EE_SUBSTAGES_NO_B6_pie={'A1-A3: ';'A4: ';'A5: ';'B4: ';'C1:
';'C2: ';'C3: ';'C4: '};
```

BAR PLOTS with use stage

LCA substages grouped with B6

```
R1 = (BASELINE_EE_TOTAL_EE_SI_B6_substages(1,1:end-1));
R2 = (BASELINE_E_SUBT_TOTAL_EE_SI_B6);
R2_pie = (BASELINE_E_SUBT_TOTAL_EE_SI_B6(1,1:end-1));
R3 = (BASELINE_EE_TOTAL_EC_SI_B6_substages(1,1:end-1));
R4 = (BASELINE_E_SUBT_TOTAL_EC_SI_B6);
R4_pie = (BASELINE_E_SUBT_TOTAL_EC_SI_B6(1,1:end-1));

% LCA substages grouped without B6
```

```
R5 = (BASELINE_EE_TOTAL_EE_NO_B6_substages(1,1:end-1));
R6_pie = (BASELINE_E_SUBT_TOTAL_EE_NO_B6(1,1:end-1));
R6 = (BASELINE_E_SUBT_TOTAL_EE_NO_B6);
R7 = (BASELINE_EE_TOTAL_EC_NO_B6_substages(1,1:end-1));
R8 = (BASELINE_E_SUBT_TOTAL_EC_NO_B6);
R8_pie = (BASELINE_E_SUBT_TOTAL_EC_NO_B6(1,1:end-1));

% LCA substages divides with B6
R9 = (BASELINE_EE_SUBT_TOTAL_EE_SI_B6(1,1:end-1));
R10 = (BASELINE_EE_SUBT_TOTAL_EC_SI_B6(1,1:end-1));

% LCA substages divides without B6
```

Stacked BAR GRAPH WITH B6:

EMBODIED CARBON

```
BASELINE_EE_SUBT_TOTAL_EC_A =
[BASELINE_EE_SUBT_TOTAL_EC_SI_B6(1,1:7),zeros(1,10)];
BASELINE_EE_SUBT_TOTAL_EC_B_SI_B6 =
[zeros(1,7),BASELINE_EE_SUBT_TOTAL_EC_SI_B6(1,8:12),zeros(1,5)];
BASELINE_EE_SUBT_TOTAL_EC_B_NO_B6 =
[zeros(1,7),BASELINE_EE_SUBT_TOTAL_EC_NO_B6(1,8:11),zeros(1,6)];
BASELINE_EE_SUBT_TOTAL_EC_C =
[zeros(1,12),BASELINE_EE_SUBT_TOTAL_EC_SI_B6(1,13:16),0];
BASELINE_EE_SUBT_TOTAL_EC_TOTAL_SI_B6 =
[zeros(1,16),BASELINE_EE_SUBT_TOTAL_EC_SI_B6(1,17)+BASELINE_EE_SUBT_TOTAL
_EC_SI_B6(1,12)];
BASELINE_EE_SUBT_TOTAL_EC_TOTAL_NO_B6 =
[zeros(1,16),BASELINE_EE_SUBT_TOTAL_EC_NO_B6(1,16)];
BASELINE_EC_STACKED_B6_SI_B6 =
[BASELINE_EE_SUBT_TOTAL_EC_A;BASELINE_EE_SUBT_TOTAL_EC_B_SI_B6;BASELINE_E
E_SUBT_TOTAL_EC_C;BASELINE_EE_SUBT_TOTAL_EC_TOTAL_SI_B6];
R12 = BASELINE_EC_STACKED_B6_SI_B6;
BASELINE_EC_STACKED_B6_NO_B6 =
[BASELINE_EE_SUBT_TOTAL_EC_A;BASELINE_EE_SUBT_TOTAL_EC_B_NO_B6;BASELINE_E
E_SUBT_TOTAL_EC_C;BASELINE_EE_SUBT_TOTAL_EC_TOTAL_NO_B6];
R14 = BASELINE_EC_STACKED_B6_NO_B6;

% EMBODIED ENERGY
BASELINE_EE_SUBT_TOTAL_EE_A_SI_B6 =
[BASELINE_EE_SUBT_TOTAL_EE_SI_B6(1,1:7),zeros(1,10)];
BASELINE_EE_SUBT_TOTAL_EE_B_SI_B6 =
[zeros(1,7),BASELINE_EE_SUBT_TOTAL_EE_SI_B6(1,8:12),zeros(1,5)];
BASELINE_EE_SUBT_TOTAL_EE_B_NO_B6 =
[zeros(1,7),BASELINE_EE_SUBT_TOTAL_EE_NO_B6(1,8:11),zeros(1,6)];
BASELINE_EE_SUBT_TOTAL_EE_C_SI_B6 =
[zeros(1,12),BASELINE_EE_SUBT_TOTAL_EE_SI_B6(1,13:16),0];
BASELINE_EE_SUBT_TOTAL_EE_TOTAL_SI_B6 =
[zeros(1,16),BASELINE_EE_SUBT_TOTAL_EE_SI_B6(1,17)+BASELINE_EE_SUBT_TOTAL
_EE_SI_B6(1,12)];
```

```
 BASELINE_EE_SUBT_TOTAL_EE_TOTAL_NO_B6 =
[zeros(1,16),BASELINE_EE_SUBT_TOTAL_EE_NO_B6(1,16)];

 BASELINE_EE_STACKED_SI_B6 = [BASELINE_EE_SUBT_TOTAL_EE_A_SI_B6;
BASELINE_EE_SUBT_TOTAL_EE_B_SI_B6; BASELINE_EE_SUBT_TOTAL_EE_C_SI_B6;
BASELINE_EE_SUBT_TOTAL_EE_TOTAL_SI_B6];
 R11 = BASELINE_EE_STACKED_SI_B6;
 BASELINE_EE_STACKED_NO_B6 = [BASELINE_EE_SUBT_TOTAL_EE_A_SI_B6;
BASELINE_EE_SUBT_TOTAL_EE_B_NO_B6; BASELINE_EE_SUBT_TOTAL_EE_C_SI_B6;
BASELINE_EE_SUBT_TOTAL_EE_TOTAL_NO_B6];
 R13 = BASELINE_EE_STACKED_NO_B6;
```

BAR RESULTS:

bars with all substages divided, including B6:

```
 run RESULTS_bar1_subplots_B6
```

bars with all substages grouped, including B6:

```
 run RESULTS_bar2_subplots_B6
```

bars with all substages grouped, not including B6:

```
 run RESULTS_bar3_subplots_no_B6
```

Stacked bar results with and with and without B6:

```
 run RESULTS_bar4_subplots_B6
```

PIE results with B6:

LCA Substages grouped

```
 run RESULTS_pie1_SI_B6
 run RESULTS_pie1_SI_B6_percentage
```

LCA stages

```
 run RESULTS_pie2_SI_B6
 run RESULTS_pie2_SI_B6_percentage
```

PIE results without B6:

LCA Substages grouped

```
 run RESULTS_pie3_NO_B6
 run RESULTS_pie3_NO_B6_percentage
```

LCA stages

```
 run RESULTS_pie4_NO_B6
 run RESULTS_pie4_NO_B6_percentage
```

Combo bars results with LCA substages divided

```
 run RESULTS_bar5_combo_SI_B6
```

combo bars with grouped LCA stages

```
run RESULTS_bar6_combo_grouped_SI_B6
run RESULTS_bar7_combo_NO_B6
run RESULTS_bar8_combo_grouped_NO_B6
```

End of ©2023 SIMPLIFIED LCA USER-FRIENDLY TOOL:

```
figure(1),clf;
clc;
save(FILE_RESULTS_NAME); % save the .mat file
disp ' ';
disp ' ';
disp 'This is the End of ©2023 SIMPLIFIED LCA USER-FRIENDLY TOOL';
disp 'We hope you enjoyed the process and results could be used towards
a greener future!';
disp ' ';
disp ' ';
disp '******** THE END ********';
```

The fifth and last main program file finishes here. All program files that are executed automatically within it are highlighted in yellow and they will be shown below. In this case it applies to all graphic results coming from the "LCA tool", which will be saved in .jpg format if the user selects so.

(5.1) RESULTS_bar1_subplots_B6 – Graph 1 program file

Upper graph

```
subplot (2,1,1);
bar9 = bar(R9,0.6);
title(sprintf('%s Energy Depletion (EDEP) - scenario
%s',P_NAME,SCENARIO));
set(gca,'XTick',1:16); % number of elements on axes "X"
set(gca,'XTickLabel',R_indicator_EE_SI_B6);
xlabel('LCA substages subdivided');
ylabel('MJ');
grid on
```

Lower graph

```
subplot (2,1,2);
bar10 = bar(R10,0.6,'FaceColor','Flat');
title(sprintf('%s Global Warming Potential (GWP) - scenario
%s',P_NAME,SCENARIO));
set(gca,'XTick',1:16); % number of elements on axes "X"
set(gca,'XTickLabel',R_indicator_EE_SI_B6);
bar10.CData(1:16,:) = [.5 .8 .7;.5 .8 .7;.5 .8 .7;
                       .5 .8 .7;.5 .8 .7;.5 .8 .7;
                       .5 .8 .7;.5 .8 .7;.5 .8 .7;
                       .5 .8 .7;.5 .8 .7;.5 .8 .7;
                       .5 .8 .7;.5 .8 .7;.5 .8 .7;
                       .5 .8 .7;];
xlabel('LCA substages subdivided');
ylabel('KgCO_2e');
grid on
```

Save the image as pdf and jpg

```
disp ' ';
R_SAVE_BAR_1=input('Do you want to save results BAR_1 TO BAR_2? (Y/N):
','s');
disp ' ';

if R_SAVE_BAR_1 == 'Y'
    print(sprintf('%s RESULTS_BAR_1 EE&EC by LCA substage divided with
B6 (scenario %s)',P_NAME, SCENARIO),'-djpeg','-r400');
    % print(sprintf('%s_BAR Base-EE&EC by LCA stage with B6',P_NAME),'-
dpng');
    % print(sprintf('%s_BAR Base-EE&EC by LCA stage with B6',P_NAME),'-
dpdf','-bestfit');
else
    disp 'Results have not been saved';
    disp 'Thanks for using the results tools';
end
```

(5.2) RESULTS_bar2_subplots_B6 – Graph 2 program file

```
figure(1),clf
```

Left-upper corner

```
subplot (2,2,1);
bar1 = bar(R1,0.5);
title(sprintf('%s Energy Depletion (EDEP) - scenario
%s',P_NAME,SCENARIO));
set(gca,'XTick',1:9); % number of elements on axes "X"
set(gca,'XTickLabel',R_indicator_EE_SUBSTAGES_SI_B6);
xlabel('LCA substages (including B6)');
ylabel('MJ');
grid on
```

Rigth-upper corner

```
subplot (2,2,2);
bar2 = bar(R2,0.4,'FaceColor','Flat');
title(sprintf('%s Energy Depletion (EDEP) - scenario
%s',P_NAME,SCENARIO));
set(gca,'XTickLabel',R_indicator_E_TOTAL);
bar2.CData(end,:) = [0.466 0.674 0.188];
xlabel('LCA stages (including B6)');
ylabel('MJ');
grid on
```

Left-down corner

```
subplot (2,2,3);
bar3 = bar(R3,0.5,'FaceColor','Flat');
title(sprintf('%s Global Warming Potential (GWP) - scenario
%s',P_NAME,SCENARIO));
set(gca,'XTick',1:9); % number of elements on axes "X"
set(gca,'XTickLabel',R_indicator_EE_SUBSTAGES_SI_B6);
bar3.CData(1:9,:) = [.5 .8 .7;.5 .8 .7;.5 .8 .7;.5 .8 .7;.5 .8 .7;.5 .8
.7;.5 .8 .7;.5 .8 .7;.5 .8 .7];
xlabel('LCA substages (including B6)');
ylabel('KgCO_2e');
grid on
```

Right-down corner

```
subplot (2,2,4);
bar4 = bar (R4, 0.4,'FaceColor','Flat');
title(sprintf('%s Global Warming Potential (GWP) - scenario
%s',P_NAME,SCENARIO));
set(gca,'XTickLabel',R_indicator_E_TOTAL);
bar4.CData(1:3,:) = [.5 .8 .7;.5 .8 .7;.5 .8 .7];
bar4.CData(4,:) = [.8 .8 .18];
xlabel('LCA stages (including B6)');
```

```
 ylabel('KgCO_2e');
 grid on
```

Save the image as pdf and jpg

```
 disp ' ';
 R_SAVE_BAR_2=input('Do you want to save results BAR_2 TO BAR_6? (Y/N):
','s');
 disp ' ';

 if R_SAVE_BAR_2 == 'Y'
     print(sprintf('%s RESULTS_BAR_2 EE&EC by LCA stage with B6 (scenario
%s)',P_NAME, SCENARIO),'-djpeg');
 else
     disp ' ';
     disp 'Results have not been saved';
     disp 'Thanks for using the results tools';
 end
```

(5.3) RESULTS_bar3_subplots_NO_B6 – Graph 3 program file

```
 figure(1),clf
```

Left-upper corner

```
 subplot (2,2,1);
 bar5 = bar(R5,0.5);
 title(sprintf('%s Energy Depletion (EDEP) - scenario
%s',P_NAME,SCENARIO));
 set(gca,'XTick',1:8); % number of elements on axes "X"
 set(gca,'XTickLabel',R_indicator_EE_SUBSTAGES_NO_B6);
 xlabel('LCA substages');
 ylabel('MJ');
 grid on
```

Rigth-upper corner

```
 subplot (2,2,2);
 bar6 = bar(R6, 0.4,'FaceColor','flat');
 title(sprintf('%s Energy Depletion (EDEP) - scenario
%s',P_NAME,SCENARIO));
 set(gca,'XTickLabel',R_indicator_E_TOTAL);
 bar6.CData(4,:) = [0.466 0.674 0.188];
 xlabel('LCA stages');
 ylabel('MJ');
 grid on
 % grid minor
```

Left-down corner

```
 subplot (2,2,3);
```

```
bar7 = bar(R7,0.5,'FaceColor','Flat');
title(sprintf('%s Global Warming Potential (GWP) - scenario
%s',P_NAME,SCENARIO));
set(gca,'XTick',1:8); % number of elements on axes "X"
set(gca,'XTickLabel',R_indicator_EE_SUBSTAGES_NO_B6);
bar7.CData(1:8,:) = [.5 .8 .7;.5 .8 .7;.5 .8 .7;.5 .8 .7;.5 .8 .7;.5 .8
.7;.5 .8 .7;.5 .8 .7];
xlabel('LCA substages');
ylabel('KgCO_2e');
grid on
```

Right-down corner

```
subplot (2,2,4);
bar8 = bar(R8, 0.4,'FaceColor','Flat');
title(sprintf('%s Global Warming Potential (GWP) - scenario
%s',P_NAME,SCENARIO));
set(gca,'XTickLabel',R_indicator_E_TOTAL);
bar8.CData(1:3,:) = [.5 .8 .7;.5 .8 .7;.5 .8 .7];
bar8.CData(4,:) = [.8 .8 .18];
xlabel('LCA stages');
ylabel('KgCO_2e');
grid on
```

Save the image as pdf and jpg

```
disp ' ';
R_SAVE_BAR_3=input('Do you want to save results BAR_7 TO BAR_10? (Y/N):
','s');
disp ' ';

if R_SAVE_BAR_3 == 'Y'


    print(sprintf('%s RESULTS_BAR_3 EE&EC by LCA stage no B6 (scenario
%s)',P_NAME, SCENARIO),'-djpeg');
    % print('BAR Results for Baseline-EE&EC by LCA Stages without B6','-
dpng');
    % print('BASELINE - BAR LCA STAGES-EE&EC','-dpdf');
else
    disp ' ';
    disp 'Results have not been saved';
    disp 'Thanks for using the results tools';
end
```

(5.4) RESULTS_bar4_subplots_B6 – Graph 4 program file

```
figure(1),clf
```

STACKED BAR RESULTS by LCA stages with B6:

Top left corner with B6

```
subplot (2,2,1);
bar11 = bar(R11,0.5,'stacked','FaceColor','Flat');
title(sprintf('%s Energy Depletion (EDEP) - scenario
%s',P_NAME,SCENARIO));
set(gca,'XTickLabel',R_indicator_E_TOTAL);
bar11(12).CData = [0.4 0.4 0.4]; % change color of B6 bar
bar11(17).CData = [0.466 0.674 0.188]; % change color of total bar
xlabel('stacked LCA stages (including B6)');
ylabel('MJ');
grid on

% other way to change bar colors
% for i = 17
%     % myColors = [zeros(16,3);0.466 0.674 0.188];
%     % colorSet = [colorSet myColors];
%     bar11(i).FaceColor = 'flat';
%     bar11(i).CData = [0.466 0.674 0.188];
%   end
```

Down left corner with B6

```
subplot (2,2,3);
bar12 = bar(R12,0.5,'stacked','FaceColor','Flat');
title(sprintf('%s Global Warming Potential (GWP) - scenario
%s',P_NAME,SCENARIO));
set(gca,'XTickLabel',R_indicator_E_TOTAL);
bar12(12).CData = [0.4 0.4 0.4]; % change color of B6 bar
bar12(17).CData = [.8 .8 .18]; % change color of total bar
% bar12(17).LineWidth = 1; % change bar exterior line width
xlabel('stacked LCA stages (including B6)');
ylabel('KgCO_2e');
grid on
% % Put exterior line in red for second input of each group.
% b(2).LineWidth = 1;
% bar(17).EdgeColor = 'red';
```

Results by LCA stages without B6:

Top rigth corner without B6

```
subplot (2,2,2);
bar13 = bar(R13,0.5,'stacked','FaceColor','Flat');
title(sprintf('%s Energy Depletion (EDEP) - scenario
%s',P_NAME,SCENARIO));
set(gca,'XTickLabel',R_indicator_E_TOTAL);
```

```
bar13(17).CData = [0.466 0.674 0.188]; % change color of total bar
xlabel('stacked LCA stages (not including B6)');
ylabel('MJ');
grid on
```

Down right corner without B6

```
subplot (2,2,4);
bar14 = bar(R14,0.5,'stacked','FaceColor','Flat');
title(sprintf('%s Global Warming Potential (GWP) - scenario
%s',P_NAME,SCENARIO));
set(gca,'XTickLabel',R_indicator_E_TOTAL);
bar14(17).CData = [.8 .8 .18];
xlabel('stacked LCA stages (not including B6)');
ylabel('KgCO_2e');
grid on
% % Put exterior line in red for second input of each group.
% b(2).LineWidth = 1;
% bar(17).EdgeColor = 'red';
```

Save the image as pdf and jpg

```
disp ' ';
R_SAVE_BAR_4=input('Do you want to save results BAR_11 TO BAR_14? (Y/N):
','s');
disp ' ';

if R_SAVE_BAR_4 == 'Y'
    print(sprintf('%s RESULTS_BAR_4 EE&EC by stacked LCA stage (scenario
%s)',P_NAME, SCENARIO),'-djpeg');
    % print(sprintf('%s_BAR Base-EE&EC by LCA stage with B6',P_NAME),'-
dpng');
    % print(sprintf('%s_BAR Base-EE&EC by LCA stage with B6',P_NAME),'-
dpdf','-bestfit');
else
    disp ' ';
    disp 'Results have not been saved';
    disp 'Thanks for using the results tools';
end
```

(5.5) RESULTS_bar5_combo_SI_B6 – Graph 5 program file

Figure with Embodied Energy and Carbon together

```matlab
figure(1),clf
subplot (1,2,1);
x2 = 0:15;

y3 = BASELINE_EE_SUBT_TOTAL_EE_SI_B6(1,1:end-1);
y4 = BASELINE_EE_SUBT_TOTAL_EC_SI_B6(1,1:end-1);

[hAx,hLine1,hLine2] = plotyy(x2,y3,x2,y4,'bar','stem');

% Change line specs for bar
hLine1.LineStyle = '-'; % Setting line style for bars
% hLine1.FaceColor = [0,0.5,0.5]; % Setting bars color
hLine1.BarWidth = 0.6;

% Change line specs for plot (stem), which are the lines:
% hLine2.LineStyle = ':'; % Setting line style
hLine2.Marker = 'o'; % Setting marker style, the circle at the top
hLine2.MarkerSize = 4; % Setting marker size, the circle at the top
hLine2.MarkerEdgeColor = 'b'; % Setting line color of the circle at the
top
% hLine2.MarkerEdgeColor = [.5 .8 .7;]; % Setting line color of the
circle at the top
% hLine2.MarkerFaceColor = 'g'; % Setting face color of the circle at
the top
hLine2.MarkerFaceColor = [.5 .8 .7;]; % Setting face color of the circle
at the top
hLine2.LineWidth = 1; % Setting line width
hLine2.Color = 'b'; % Setting line color
% hLine2.Color = [.5 .8 .7;]; % Setting line color
set(gca,'XTick',0:15); % set number of items on x-axis
set(gca,'XTickLabel',R_indicator_EE_SI_B6); % set names attached to each
x-axis data
ylabel(hAx(1),'Megajoules (MJ)') % left y-axis title
% ylim(hAx(1),[0 3*10^8]) % Set y-axis limits. Works for left axis
% set(hAx(1),'YTick',0:0.5*10^8:5*10^8); % Set separation of markers on
Y-axis left side
ylabel(hAx(2),'Global Warming Potential (KgCO_2e)') % right y-axis title
% ylim(hAx(2),[0 1.5*10^7]) % Set y-axis limits. Works for right axis
% set(hAx(2),'YTick',0:0.25*10^7:3.4*10^7); % Set separation of markers
on Y-axis right side
title(sprintf('%s EE&EC with B6 - scenario %s',P_NAME,SCENARIO))
xlabel('LCA substages divided')
grid on
grid minor
```

(5.6) RESULTS_bar6_combo_grouped_SI_B6 – Graph 6 program file

figure with Embodied Energy and Carbon together

```
% figure(1),clf
subplot(1,2,2);
x3 = 0:8;

[hAx,hLine1,hLine2] = plotyy(x3,R1,x3,R3,'bar','stem');

% Change line specs for bar
hLine1.LineStyle = '-'; % Setting line style for bars
% hLine1.FaceColor = [0,0.5,0.5]; % Setting bars color
hLine1.BarWidth = 0.5;

% Change line specs for plot (stem), which are the lines:
% hLine2.LineStyle = ':'; % Setting line style
hLine2.Marker = 'o'; % Setting marker style, the circle at the top
hLine2.MarkerSize = 4; % Setting marker size, the circle at the top
hLine2.MarkerEdgeColor = 'b'; % Setting line color of the circle at the
top
% hLine2.MarkerEdgeColor = [.5 .8 .7;]; % Setting line color of the
circle at the top
% hLine2.MarkerFaceColor = 'g'; % Setting face color of the circle at
the top
hLine2.MarkerFaceColor = [.5 .8 .7;]; % Setting face color of the circle
at the top
hLine2.LineWidth = 1; % Setting line width
hLine2.Color = 'b'; % Setting line color
% hLine2.Color = [.5 .8 .7;]; % Setting line color

set(gca,'XTick',0:8); % set number of items on x-axis
set(gca,'XTickLabel',R_indicator_EE_SUBSTAGES_SI_B6); % set names
attached to each x-axis data

ylabel(hAx(1),'Megajoules (MJ)') % left y-axis title
% ylim(hAx(1),[0 3*10^7]) % Set y-axis limits. Works for left axis
% set(hAx(1),'YTick',0:0.75*10^7:5*10^7); % Set separation of markers on
Y-axis left side

ylabel(hAx(2),'Global Warming Potential (KgCO_2e)') % right y-axis title
% ylim(hAx(2),[0 2*10^6]) % Set y-axis limits. Works for right axis
% set(hAx(2),'YTick',0:0.5*10^6:3.4*10^6); % Set separation of markers
on Y-axis right side

title(sprintf('%s EE&EC with B6 - scenario %s',P_NAME,SCENARIO))
xlabel('LCA substages grouped')
grid on
grid minor
```

Save the image as .jpg

```
 disp ' ';
 R_SAVE_BAR_7=input('Do you want to save results BAR_15 & BAR_16? (Y/N):
','s');
 disp ' ';

 if R_SAVE_BAR_7 == 'Y'
     print(sprintf('%s RESULTS_BAR_5_6 EE&EC COMBO by LCA substage with
B6 (scenario %s)',P_NAME, SCENARIO),'-djpeg','-r400');
     % print(sprintf('%s_BAR Base-EE&EC by LCA stage with B6',P_NAME),'-
dpng');
     % print(sprintf('%s_BAR Base-EE&EC by LCA stage with B6',P_NAME),'-
dpdf','-bestfit');
 else
     disp ' ';
     disp 'Results have not been saved';
     disp 'Thanks for using the results tools';
 end
```

(5.7) RESULTS_bar7_combo_NO_B6 – Graph 7 program file

figure with Embodied Energy and Carbon together

```
 figure(1),clf
 subplot (1,2,1);
 x = 0:14;

 y1 = BASELINE_EE_SUBT_TOTAL_EE_NO_B6(1,1:end-1);
 y2 = BASELINE_EE_SUBT_TOTAL_EC_NO_B6(1,1:end-1);

 [hAx,hLine1,hLine2] = plotyy(x,y1,x,y2,'bar','stem');

 % Change line specs for bar
 hLine1.LineStyle = '-'; % Setting line style for bars
 % hLine1.FaceColor = [0,0.5,0.5]; % Setting bars color
 hLine1.BarWidth = 0.6;

 % Change line specs for plot (stem), which are the lines:
 % hLine2.LineStyle = ':'; % Setting line style
 hLine2.Marker = 'o'; % Setting marker style, the circle at the top
 hLine2.MarkerSize = 4; % Setting marker size, the circle at the top
 hLine2.MarkerEdgeColor = 'b'; % Setting line color of the circle at the
top
 % hLine2.MarkerEdgeColor = [.5 .8 .7;]; % Setting line color of the
circle at the top
 % hLine2.MarkerFaceColor = 'g'; % Setting face color of the circle at
the top
 hLine2.MarkerFaceColor = [.5 .8 .7;]; % Setting face color of the circle
at the top
 hLine2.LineWidth = 1; % Setting line width
```

```
 hLine2.Color = 'b'; % Setting line color
 % hLine2.Color = [.5 .8 .7;]; % Setting line color
 set(gca,'XTick',0:14); % set number of items on x-axis
 set(gca,'XTickLabel',R_indicator_EE_NO_B6); % set names attached to each
x-axis data
 ylabel(hAx(1),'Megajoules (MJ)') % left y-axis title
 % ylim(hAx(1),[0 1.5*10^6]) % Set y-axis limits. Works for left axis
 % set(hAx(1),'YTick',0:25*10^4:2*10^6); % Set separation of markers on
Y-axis left side
 ylabel(hAx(2),'Global Warming Potential (KgCO_2e)') % right y-axis title
 % ylim(hAx(2),[0 3*10^5]) % Set y-axis limits. Works for right axis
 % set(hAx(2),'YTick',0:0.5*10^5:3*10^5); % Set separation of markers on
Y-axis right side
 title(sprintf('%s EE&EC without B6 - scenario %s',P_NAME,SCENARIO))
 xlabel('LCA substages divided')
 grid on
 grid minor
```

(5.8) RESULTS_bar8_combo_grouped_NO_B6 – Graph 8 program file

figure with Embodied Energy and Carbon together

```
 subplot(1,2,2);
 x4 = 0:7;

 [hAx,hLine1,hLine2] = plotyy(x4,R5,x4,R7,'bar','stem',0.2);

 % *** Change line specs for bar ***
 hLine1.LineStyle = '-'; % Setting line style for bars
 % hLine1.FaceColor = [0,0.5,0.5]; % Setting bars color
 hLine1.BarWidth = 0.5;

 % *** Change line specs for plot (stem), which are the lines ***
 % hLine2.LineStyle = ':'; % Setting line style to dots type.
 hLine2.Marker = 'o'; % Setting marker style, the circle at the top
 hLine2.MarkerSize = 4; % Setting marker size, the circle at the top
 hLine2.MarkerEdgeColor = 'b'; % Setting line color of the circle at the
top
 % hLine2.MarkerEdgeColor = [.5 .8 .7;]; % Setting line color of the
circle at the top
 % hLine2.MarkerFaceColor = 'g'; % Setting face color of the circle at
the top
 hLine2.MarkerFaceColor = [.5 .8 .7;]; % Setting face color of the circle
at the top
 hLine2.LineWidth = 1; % Setting line width
 hLine2.Color = 'b'; % Setting line color
 % hLine2.Color = [.5 .8 .7;]; % Setting line color

 % *** Change axes and title options ***
```

```
 set(gca,'XTick',0:7); % set number of items on x-axis
 set(gca,'XTickLabel',R_indicator_EE_SUBSTAGES_NO_B6); % set names
attached to each x-axis data

 ylabel(hAx(1),'Megajoules (MJ)') % left y-axis title
 % ylim(hAx(1),[0 1.5*10^6]) % Set y-axis limits. Works for left axis
 % set(hAx(1),'YTick',0:25*10^4:2*10^6); % Set separation of markers on
Y-axis left side

 ylabel(hAx(2),'Global Warming Potential (KgCO_2e)') % right y-axis title
 % ylim(hAx(2),[0 3*10^5]) % Set y-axis limits. Works for right axis
 % set(hAx(2),'YTick',0:0.5*10^5:2.5*10^5); % Set separation of markers
on Y-axis right side

 title(sprintf('%s EE&EC with B6 - scenario %s',P_NAME,SCENARIO))
 xlabel('LCA substages grouped')
 grid on
 grid minor
```

Save the image as .jpg

```
 disp ' ';
 R_SAVE_BAR_8=input('Do you want to save results BAR_17 & BAR_18? (Y/N):
','s');
 disp ' ';

 if R_SAVE_BAR_8 == 'Y'
     print(sprintf('%s RESULTS_BAR_7_8 EE&EC COMBO by LCA substage
without B6 (scenario %s)',P_NAME, SCENARIO),'-djpeg','-r400');
 else
     disp ' ';
     disp 'Results have not been saved';
     disp 'Thanks for using the results tools';
 end
```

(5.9) RESULTS_pie1_SI_B6_percentage – Graph 9 program file

PIE CHART INCLUDING B6

With all Substages grouped:

Energy:

```
explode1 = [1 1 1 1 1 1 1 1 1];
labels1 = {'','','','','','','','',''};
subplot(1,2,1);
pie1_2 = pie(R1,explode1);
title(sprintf('%s (EDEP) - scenario  %s',P_NAME,SCENARIO));

pie1Text = findobj(pie1_2,'Type','text');
percentValues1 = get(pie1Text,'String');
combinedtxt_pie1 =
strcat(R_indicator_EE_SUBSTAGES_SI_B6_pie,percentValues1);
% legend(R_indicator_EE_SUBSTAGES_SI_B6);
legend(combinedtxt_pie1);
```

Carbon:

```
subplot(1,2,2);
pie2_2 = pie(R3,explode1);
title(sprintf('%s (GWP) - scenario  %s',P_NAME,SCENARIO));
pie2Text = findobj(pie2_2,'Type','text');
percentValues2 = get(pie2Text,'String');
combinedtxt_pie2 =
strcat(R_indicator_EE_SUBSTAGES_SI_B6_pie,percentValues2);

legend(combinedtxt_pie2);
```

Save the image as pdf and jpg:

```
disp ' ';
R_SAVE_PIE_1_2=input('Do you want to save results PIE_1 & PIE_2 with
percentages? (Y/N): ','s');
disp ' ';

if R_SAVE_PIE_1_2 == 'Y'
    print(sprintf('%s RESULTS_PIE_1 EE&EC by LCA STAGES with B6
pecentages (scenario %s)',P_NAME,SCENARIO),'-djpeg');
else
    disp ' ';
    disp 'Results have not been saved';
    disp 'Thanks for using the results tools';
end
```

(5.10) RESULTS_pie1_SI_B6 – Graph 10 program file

PIE CHART INCLUDING B6

With all Substages grouped:

Energy

```
explode1 = [1 1 1 1 1 1 1 1 1];
labels1 = {'','','','','','','','',''};
subplot(1,2,1);
pie1_2 = pie(R1,explode1,labels1);
title(sprintf('%s (EDEP) - scenario  %s',P_NAME,SCENARIO));
```

Carbon

```
subplot(1,2,2);
pie2_2 = pie(R3,explode1,labels1);
title(sprintf('%s (GWP) - scenario  %s',P_NAME,SCENARIO));

legend(R_indicator_EE_SUBSTAGES_SI_B6);
```

Save the image as pdf and jpg

```
disp ' ';
R_SAVE_PIE_1=input('Do you want to save results PIE_3 & PIE_4? (Y/N):
','s');
disp ' ';

if R_SAVE_PIE_1 == 'Y'
    print(sprintf('%s RESULTS_PIE_2 EE&EC by LCA STAGES with B6
(scenario %s)',P_NAME,SCENARIO),'-djpeg');
else
    disp ' ';
    disp 'Results have not been saved';
    disp 'Thanks for using the results tools';
end
```

(5.11) RESULTS_pie2_SI_B6_percentage – Graph 11 program file

With stages A, B and C:

Energy

```
subplot(1,2,1);
explode2 = [1 1 1];
labels2 = {'','',''};
pie3 = pie(R2_pie,explode2);
title(sprintf('%s (EDEP) - scenario  %s',P_NAME,SCENARIO));

pie3Text = findobj(pie3,'Type','text');
percentValues3 = get(pie3Text,'String');
combinedtxt_pie3 = strcat(R_indicator_E_pie,percentValues3);

legend(combinedtxt_pie3);
```

Carbon

```
subplot(1,2,2);
pie4 = pie(R4_pie,explode2);
title(sprintf('%s (GWP) - scenario %s',P_NAME,SCENARIO));

pie4Text = findobj(pie4,'Type','text');
percentValues4 = get(pie4Text,'String');
combinedtxt_pie4 = strcat(R_indicator_E_pie,percentValues4);

legend(combinedtxt_pie4);
```

Save the image as pdf and jpg

```
disp ' ';
R_SAVE_PIE_2_2=input('Do you want to save results PIE_5 & PIE_6 with
percentages? (Y/N): ','s');
disp ' ';

if R_SAVE_PIE_2_2 == 'Y'
    print(sprintf('%s RESULTS_PIE_3 EE&EC by LCA STAGES with B6
percentages (scenario %s)',P_NAME,SCENARIO),'-djpeg');
else
    disp ' ';
    disp 'Results have not been saved';
    disp 'Thanks for using the results tools';
end
```

(5.12) RESULTS_pie2_SI_B6 – Graph 12 program file

With stages A, B and C:

Energy

```
subplot(1,2,1);
explode2 = [1 1 1];
labels2 = {'','',''};
pie3 = pie(R2_pie,explode2,labels2);
title(sprintf('%s (EDEP) - scenario  %s',P_NAME,SCENARIO));
```

Carbon

```
subplot(1,2,2);
pie4 = pie(R4_pie,explode2,labels2);
title(sprintf('%s (GWP) - scenario %s',P_NAME,SCENARIO));

legend(R_indicator_E);
```

Save the image as pdf and jpg

```
disp ' ';
R_SAVE_PIE_2=input('Do you want to save results PIE_7 & PIE_8? (Y/N):
','s');
disp ' ';

if R_SAVE_PIE_2 == 'Y'
    print(sprintf('%s RESULTS_PIE_4 EE&EC by LCA STAGES with B6
(scenario %s)',P_NAME,SCENARIO),'-djpeg');
else
    disp ' ';
    disp 'Results have not been saved';
    disp 'Thanks for using the results tools';
end
```

(5.13) RESULTS_pie3_NO_B6_percentage – Graph 13 program file

PIE CHART INCLUDING B6

with all Substages grouped:

ENERGY

```
explode3 = [1 1 1 1 1 1 1 1 ];
labels3 = {'','','','','','','',''};
subplot(1,2,1);
pie5_2 = pie(R5,explode3);
title(sprintf('%s (EDEP) - scenario  %s',P_NAME,SCENARIO));

pie5Text = findobj(pie5_2,'Type','text');
percentValues5 = get(pie5Text,'String');
combinedtxt_pie5 =
strcat(R_indicator_EE_SUBSTAGES_NO_B6_pie,percentValues5);

legend(combinedtxt_pie5);
```

CARBON:

```
subplot(1,2,2);
pie6_2 = pie(R7,explode3);
title(sprintf('%s (GWP) - scenario  %s',P_NAME,SCENARIO));

pie6Text = findobj(pie6_2,'Type','text');
percentValues6 = get(pie6Text,'String');
combinedtxt_pie6 =
strcat(R_indicator_EE_SUBSTAGES_NO_B6_pie,percentValues6);

legend(combinedtxt_pie6);
```

Save the image as pdf and jpg

```
disp ' ';
R_SAVE_PIE_3_2=input('Do you want to save results PIE_9 & PIE_10 with
percentages? (Y/N): ','s');
disp ' ';

if R_SAVE_PIE_3_2 == 'Y'
    print(sprintf('%s RESULTS_PIE_5 EE&EC by LCA STAGES without B6
percentage (scenario %s)',P_NAME,SCENARIO),'-djpeg');
else
    disp ' ';
    disp 'Results have not been saved';
    disp 'Thanks for using the results tools';
end
```

(5.14) RESULTS_pie3_NO_B6 – Graph 14 program file

PIE CHART INCLUDING B6

with all Substages grouped:

ENERGY

```
explode3 = [1 1 1 1 1 1 1 1 ];
labels3 = {'','','','','','','',''};
subplot(1,2,1);
pie5_2 = pie(R5,explode3,labels3);
title(sprintf('%s (EDEP) - scenario  %s',P_NAME,SCENARIO));
```

CARBON:

```
subplot(1,2,2);
pie6_2 = pie(R7,explode3,labels3);
title(sprintf('%s (GWP) - scenario  %s',P_NAME,SCENARIO));


legend(R_indicator_EE_SUBSTAGES_NO_B6);
```

Save the image as pdf and jpg

```
disp ' ';
R_SAVE_PIE_3=input('Do you want to save results PIE_11 & PIE_12? (Y/N):
','s');
disp ' ';

if R_SAVE_PIE_3 == 'Y'
    print(sprintf('%s RESULTS_PIE_6 EE&EC by LCA STAGES without B6
(scenario %s)',P_NAME,SCENARIO),'-djpeg');
else
    disp ' ';
    disp 'Results have not been saved';
    disp 'Thanks for using the results tools';
end
```

(5.15) RESULTS_pie4_NO_B6_percentage – Graph 15 program file

PIE CHART NOT INCLUDING B6

with stages A, B and C:

```
explode2 = [1 1 1];
labels2 = {'','',''};

% X = BASELINE_E_SUBT_TOTAL_EE_SI_B6(1,1:3);
subplot(1,2,1);
pie7 = pie(R6_pie,explode2);
title(sprintf('%s (EDEP) - scenario  %s',P_NAME,SCENARIO));

pie7Text = findobj(pie7,'Type','text');
percentValues7 = get(pie7Text,'String');
combinedtxt_pie7 = strcat(R_indicator_E_pie,percentValues7);

legend(combinedtxt_pie7);
```

Y = BASELINE_EE_SUBT_TOTAL_EC_SI_B6(1,1:3);

```
subplot(1,2,2);
pie8 = pie(R8_pie,explode2);
title(sprintf('%s (GWP) - scenario %s',P_NAME,SCENARIO));

pie8Text = findobj(pie8,'Type','text');
percentValues8 = get(pie8Text,'String');
combinedtxt_pie8 = strcat(R_indicator_E_pie,percentValues8);

legend(combinedtxt_pie8);
```

Save the image as pdf and jpg

```
disp ' ';
R_SAVE_PIE_4_2=input('Do you want to save results PIE_13 & PIE_14 with
percentages? (Y/N): ','s');
disp ' ';

if R_SAVE_PIE_4_2 == 'Y'
    print(sprintf('%s RESULTS_PIE_7 EE&EC by LCA STAGES without B6
pecentage (scenario %s)',P_NAME,SCENARIO),'-djpeg');
else
    disp ' ';
    disp 'Results have not been saved';
    disp 'Thanks for using the results tools';
end
```

(5.16) RESULTS_pie4_NO_B6 – Graph 16 program file

PIE CHART NOT INCLUDING B6

with stages A, B and C:

```
explode2 = [1 1 1];
labels2 = {'','',''};

% X = BASELINE_E_SUBT_TOTAL_EE_SI_B6(1,1:3);
subplot(1,2,1);
pie7 = pie(R6_pie,explode2,labels2);
title(sprintf('%s (EDEP) - scenario  %s',P_NAME,SCENARIO));

% legend(combinedtxt_pie7);
```

Y = BASELINE_EE_SUBT_TOTAL_EC_SI_B6(1,1:3);

```
subplot(1,2,2);
pie8 = pie(R8_pie,explode2,labels2);
title(sprintf('%s (GWP) - scenario %s',P_NAME,SCENARIO));



legend(R_indicator_E_pie);
```

Save the image as pdf and jpg

```
disp ' ';
R_SAVE_PIE_4_2=input('Do you want to save results PIE_15 & PIE_16 with
percentages? (Y/N): ','s');
disp ' ';

if R_SAVE_PIE_4_2 == 'Y'
    print(sprintf('%s RESULTS_PIE_8 EE&EC by LCA STAGES without B6
pecentage (scenario %s)',P_NAME,SCENARIO),'-djpeg');
else
    disp ' ';
    disp 'Results have not been saved';
    disp 'Thanks for using the results tools';
end
```