Innovation Readiness Assessment Tool for Research Centres and Businesses Collaborating in Lightweighting

by

Adam Selim

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Department of Design, Manufacturing, and Engineering Management

University of Strathclyde

GLASGOW

Declaration of Authors Rights

Signed: Adam Selim

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Abstract

This purpose of this research is to develop a tool for research centres to assess the innovation readiness of businesses approaching them to collaborate in the context of lightweighting. Lightweighting is an advanced technique, playing an important, yet peripheral role in industry that can be used to enhance performance, profits and sustainability. Though, it can be subject to misconceptions and usually requires training or skilled and experienced individuals in its application.

Through semi structured interviews, a gap in practice was identified that some businesses are wanting to collaborate with research centres in lightweighting, but they have misconceptions and misunderstandings of its application. With an influx of lightweighting enquiries, some research centres are being negatively affected. Through 2 literature reviews, one on lightweighting and the other at the intersections of research centres and innovation readiness assessment tools, many tools were found to assess collaborations between companies and research centres, but no assessment tools were identified by the author to be at that intersection.

With a pressing need for a lightweighting tailored tool in industry, this research uses a literature review synthesis to output an innovation readiness assessment tool for research centres and businesses collaborating in lightweighting, contributing to both practice and literature. A holistic and adaptive framework was developed based on the context boundaries and would be of interest to businesses who can use it to think about their own readiness and to research centres as points of discussion before engaging in collaborations in lightweighting.

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Abbreviations

AFRC	Advanced Forming Research Centre
EARTO	European Association of Research and Technology Organisations
IP	Intellectual Property
IRC	Innovation Readiness/Capability
ISO	International Organisation for Standardization
LCA	Life-Cycle Assessment
LMC	Lightweight Manufacturing Centre
LW	Lightweighting
MCF	Maturity/Capability Framework
NDA	Non-Disclosure Agreement
OI	Open Innovation
R&D	Research and Development
RC	Research Centres
RIO	Research and Innovation Organisation
RO	Research Objective
RTO	Research and Technology Organisation
SLR	Systematic Literature Review
SSI	Semi-Structured Interviews
TIC	Technology and Innovation Centre
TRL	Technology Readiness Levels
UIC	University-Industry Collaboration

Definitions

Innovation Readiness: "*the concept of providing an evaluation of the extent to which companies can sustain their ability to innovate*" (Gribbin et al., 2018) Pg 5.

Innovation Readiness Assessment: A focussed assessment on innovation readiness. It involves assessing factors both internally and externally based upon the input and intentions of the business (Gribbin et al.,2018, AFRC, 2021, Banjongprasert, 2017, Shum, 2015).

Lightweighting: The intentional design of a component or product to become lighter than it initially was or would be using standard methods, in order to perform a required task (Tempelman, 2014, Zhu et al., 2018, Fan and Njuguna, 2016).

Open Innovation: The incoming and outgoing flow of knowledge to develop innovation internally and to use of innovation output in the market (Chesbrough and Brunswicker, 2014).

Open Innovation Capability: The capacity and/or ability for a business to innovate and collaborate with external partners based on knowledge internal and external to the business (Iddris, 2016, Wu and Chen, 2010, Yaghoubi et al., 2017, Moya et al., 2020)

Open Innovation Maturity: The "extent to which a specific process is explicitly defined, managed, measured, controlled, and effective" Paulk et al. (1993) referenced in (Enkel et al., 2011) pg. 1164

Research Centres: Are institutions that conduct research, generally in a field of expertise and offer a wide range of services including software know-how, hardware capabilities, design, manufacturing processes, knowledge transfer, training, networking, providing access to technologies, private and public funding, speciality expertise services, prototyping capabilities, access to IP management, routes to volume manufacturing, knowledge and experience (Uribe-Echeberria et al., 2019, Yaghoubi et al., 2017, Hepburn and Wolfe, 2014, Hauser, 2010, Agogué et al., 2017, Giannopoulou et al., 2019). For the purposes of this research, as there are many different types of research centres, the author is looking for the commonality that they support businesses in projects of varying sizes to achieve an outcome.

Chapter 1

Introduction

1. Introduction

Research Centres (RC) have become an important staple of the British workforce in recent times due to the positive impact they have on the economy (Economics, 2014, Hauser, 2010, Commons, 2019). By implementing cutting edge research and technology from academic research into the country's manufacturing output, they participate towards the national strategy to compete on the global economic platform towards a High Value Manufacturing status. RCs have gained popularity globally with many other countries having similar strategies and already established RCs, e.g. Germany has the Fraunhofer–Gesellschaft, the US has The National Network for Manufacturing Innovation (Hepburn and Wolfe, 2014).

RCs in the UK exist primarily to contribute financially to the economy and output high quality research that can be commercially viable (Hauser, 2010, Commons, 2011, Hepburn and Wolfe, 2014). With reports recently indicating a return of investment of range between £4-£7 for every £1 invested in Innovation, The Research and Technology Sector, or Research and Development, which incorporate the UK's national model of RCs, the economic benefit can be easily identified (Economics, 2014, Commons, 2019). This "bridging the gap between academia and industry" strategy (Hauser, 2010, Commons, 2011, Hepburn and Wolfe, 2014, Network, 2019), has seen many businesses approach RCs for support, leading to a great influx of enquiries and an added pressure for RCs to sift through enquiries to find contexts which they can address and subsequently, clients they can support (Section 4.2, Tann et al., 2002).

Some RCs specialise in the context of lightweighting (LW). LW is a tool that has been gaining increasing attention amongst many industries due to the significant contribution that it can address to key drivers, such as

- Improving functionality of designs through an in-depth analysis of the manufacturing processes, material selections and design optimisations (Tempelman, 2014, Herrmann et al., 2018), and
- Increasing profitability through an improved efficiency in designs and use of materials through new manufacturing processes (Montalbo et al., 2009, Gesrepair, 2017).

- Improving sustainability through the reduction of carbon emissions and subsequently greenhouse gas emissions (Mouritz, 2012, Marino and Sabatini, 2014, Pervaiz et al., 2016, Gesrepair, 2017, Zhu et al., 2018)

With the possible advantages that LW can achieve, it can lead towards enhancing industrial developments and possibly provide a competitive edge over competition (Le Duigou et al., 2016, Zhu et al., 2018). With regulators and governments imposing sustainability criteria, such as upcoming goals of zero-net carbon emissions upon manufacturing industries, including the automotive, aerospace and others, LW has being identified by businesses as a key tool to aid them in becoming more responsible in environmental sustainability (Zhu et al., 2018, Schuh et al., 2013, Albers et al., 2019).

> "It is believed that more than a quarter of all combined greenhouse gas emissions (GHG) are associated with road transport vehicles. All these facts in association with heightened consumer awareness and energy security issues have led to automotive lightweighting as a major research theme across the globe." (Pervaiz et al., 2016) Pg. 26

Subsequently, some businesses are turning to RCs for support in LW. From the preliminary scoping interviews and undocumented/informal conversations and observations, it was noted many businesses and individuals have not been managing LW correctly through the misconceptions they had of LW. Most commonly, that LW is the use of composites or advanced materials (this is also seen in literature, (Tempelman, 2014)) and that the use of it is automatically going to be for the better, whether for performance, sustainability or profitability.

The combined effects of an influx of businesses approaching RCs for support and businesses not managing LW correctly/having misconceptions of LW, has led some RCs to spending an excessive amount of time in identifying suitable clients. This in turn can hinder an RCs performance output and make them less efficient with their time as opposed to dedicating more time to businesses they can support (Tann et al., 2002). These combined effects are interesting topics to investigate and are the focal points of this research.

1.1. Contextualising the Research

This research was funded by the Advanced Forming Research Centre and the University of Strathclyde to research the organisational changes required to successfully innovate in the context of LW. A literature review on LW indicated that extensive research has been conducted on the development of LW materials, advanced manufacturing processes and design optimisations. These three points are widely recognised and regarded to be the three key pillars of LW in literature. However, little information and research was found on the management and innovation of LW.

To help identify a research problem, the author turned to industry to find a current practical problem that are faced by businesses or RCs in the management of LW. This was achieved by conducting preliminary scoping interviews with experienced practitioners of LW. These interviews identified that RCs are receiving numerous LW enquiries by businesses that don't seem to have an understanding of LW and its applications. One candidate even noted that many businesses were asking to lightweight, but didn't know if it would be helpful to them.

Once this problem in industry was acknowledged, the research subject area became about questioning the innovation readiness of businesses and RCs collaborating in LW. A Systematic Literature Review (SLR) was conducted to find out what other researchers had done within similar subject areas. This review identified a gap in literature in this subject area and no assessment tools for this problem. In turn, a synthesis of the SLR was used to develop an assessment tool to address this gap both in literature and in practice. The aim of this assessment tool is to help RCs sift through enquiring businesses by the state of their readiness to collaborate in LW.

1.2. Research Objectives

With the scope of this research intersecting multiple subject areas, namely LW management, Research Centres, innovation readiness assessments and collaboration dynamics between RC and businesses, 4 research objectives were set that led to contributing towards the gap in knowledge and practice.

Problem in practice

Research Centres are receiving numerous LW enquiries by businesses that don't seem to have an understanding of LW and its applications.

Gap in knowledge and practice

Innovation readiness assessment tool for research centres and businesses collaborating in lightweighting.

Research Objective 1 (RO1)

Identify the management aspects of LW, it's components, influential factors and the frameworks used LW as literature has a predominant technical view on LW.

Research Objective 2 (RO2)

Identify a relevant and contemporary issue in industry on the management of lightweighting as well as find out how businesses manage lightweighting.

Note – The preliminary scoping interviews were used to address this research objective (See Chapter 4). Research Objectives 3 and 4 were identified from this and set out below.

Research Objective 3 (RO3)

Exploring linkages between businesses/RCs collaborating together and innovation readiness assessment tools, identifying influential factors and assessment tools used in literature.

Research Objective 4 (RO4)

Create an assessment tool through the synthesis of relevant literatures that would address the problem in practice.

1.3. Research Significance

This research is appropriate and timely because there is a dynamic shift of many businesses working to becoming more environmentally sustainable and upcoming regulations being imposed by governments worldwide. Lightweighting is a holistic tool that can potentially aid in achieving these sustainability goals through considering newer ways of manufacturing, using different materials, utilising advanced design strategies and streamlining the product's lifecycle. (Tempelman, 2014, Luedeke et al., 2014a, Kaspar and Vielhaber, 2017, Karakoyun et al., 2014). This research seeks to output an assessment tool that will aid research centres in identifying the innovation readiness levels of companies seeking to collaborate with them in lightweighting. This is important for the following reasons,

1- Contribution to practice: The novelty of the assessment tool would directly aim to address the problem identified in practice. This aims to streamline the process of finding potential collaboration partners as well as educate enquiring businesses of their readiness levels and areas in which they can improve. Furthermore, it would give the research centres an idea of how they can tailor their support for these businesses.
2- Contribution to knowledge: By bringing together different academic areas, this new subject area would seek to build upon the foundations of the literatures that intersect with one another and contribute with an assessment tool.

1.4. Thesis Structure

The start of each chapter will address the purpose and outcomes of that chapter. The thesis comprises of 7 chapters. Figure 1.1 below illustrates the layout of the thesis to aid the reader. Note that the position of the lightweighting context is prior to the preliminary scoping interviews so that the interviews can be understood better as there are many references to lightweighting.

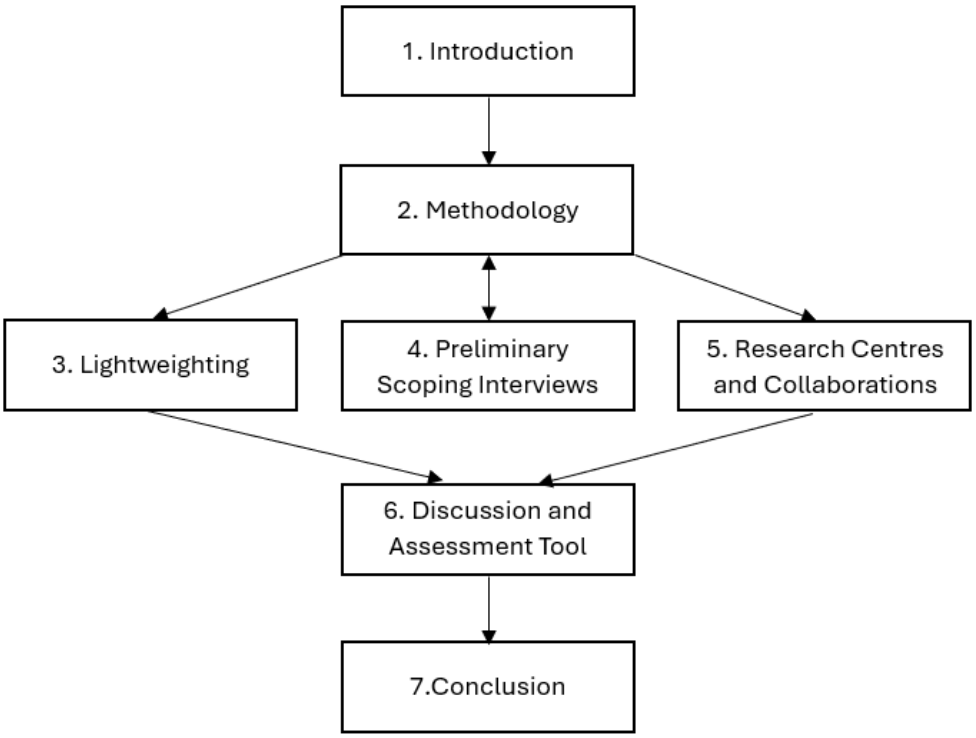

Figure 1.1 - Thesis Layout

Below contains a brief outline of what each chapter presents and how the research objectives are achieved in each of them. They are as follows,

Chapter 1 – Introduction

This chapter frames the context of the research, introduces the topic and states the identified gaps in knowledge and practice identified.

Chapter 2 – Methodology

This chapter focuses on the research philosophy and design used. The methodology follows the Research Onion developed by Saunders, Lewis and Thornhill (2008). This includes developing a research philosophy, approach to theory development, methodological choices, strategies, time horizon and techniques and procedures implemented.

Chapter 3 – Literature Review on the Lightweighting Context

This chapter will examine literature on LW, detailing key points to develop a theoretical understanding which will aid in identifying key attributes, techniques and issues that can provide context for the assessment tool. This chapter on LW has been placed at this stage in the thesis to provide context to the other chapters.

Research objectives contribution: This chapter directly addresses the first research objective, where the management aspects of LW are detailed and discussed, including, the components of LW, influential factors and frameworks used.

Chapter 4 – Preliminary Scoping Interviews

This chapter will discuss the preliminary scoping interviews conducted to identify a practical and appropriate issue in industry as well as find out how businesses manage lightweighting.

Research objectives contribution: This section contributes to the second research objective by identifying a relevant and contemporary issue in industry in managing lightweighting.

Chapter 5 – Literature Review on Research Centres and Collaborations

This chapter will elaborate on the systematic literature review process, the literature on businesses/RCs collaborating together and the innovation tools/frameworks used by researchers in similar contexts. The theoretical concepts derived from this will be examined and considered for the development of a conceptual assessment tool.

Research objectives contribution: This section contributes to the third research objective, where a review of literature is conducted, the dynamics of RC/business collaborations are discussed and innovation readiness tools used in the assessments of collaborations are detailed and elaborated upon.

Chapter 6 – Discussion and Assessment Tool Development

This chapter sets to discuss the findings from the data collection phase and design an assessment tool that derives from the findings which is tailored to the context.

Research objectives contribution: This chapter contributes to the fourth research objective This chapter discusses the findings of the literature reviews and identifies a gap in knowledge that ties up with a gap in practice. Furthermore, it develops an assessment tool through the synthesis of relevant literatures and address the problem in practice.

Chapter 7 – Conclusions

Finally, the thesis will conclude with a critical review of the research objectives, critique the findings and assessment tool, research conclusions, identify the contribution to knowledge and discuss future research directions.

Chapter 2

Research Methodology

2. Research Methodology

Chapter Purpose	To define the research philosophy and research design used.
Chapter Output	The purpose is addressed through elaborating on research philosophy, approach to theory development, methodological choice, strategy, time horizon and techniques and procedures.

There is a significant amount of literature on methodologies with many avenues in which one can conduct research. To try and discuss them all is exhaustive and would be out with the scope of this thesis. Instead, this section will elaborate on the route that was taken to develop and conduct this research. To define the research methodology, the research onion by Saunders, Lewis and Thornhill (2008) was applied to account for considerations one should make during research. That is, define the research philosophy, the approach to theory development, methodological choices, strategies, time horizon and techniques/procedures. The following sections will elaborate further on these layers and the end of the chapter will present a summary of the research design.

2.1. Research Philosophy

The type of philosophy adopted in this research came to realisation through the use of the reflexive tool called HARP (Heightened Awareness of Research Philosophy) by Saunders and Bristow (2014). This tool which is aptly named, asks a series of questions to find potential matches between the authors own beliefs and predominant philosophies in business and management literature (Saunders, 2019). 3 main philosophies were shortlisted through the use of the HARP tool. Namely, critical realism, interpretivism and pragmatism. From this review, the prime philosophy identified and implemented in this research is the pragmatism philosophy.

This philosophical stance was reached through the review of the ontology, epistemology and axiology of these philosophies. To provide a bit of context of what the 'ologies' are, the existence of many philosophical positions is because there is more than one way to view and solve a problem. How this

problem is solved depends on the viewpoint of the researcher. More specifically, the outlook that they have on the nature of reality, their assumptions of knowledge and their values and ethics. These points are more commonly known as ontology, epistemology and axiology respectively (Saunders, 2019). Table 2.1 below, sourced from Saunders (2019), is a table comparing the shortlisted philosophies with respect to the 'ologies' and typical methods used.

Research Philosophical position	**Critical Realism**	**Interpretivism**	**Pragmatism**
Ontology	Stratified/Layered, (the empirical, the actual and the real) External, independent Intransient Objective structures Causal mechanisms	Complex, rich Socially constructed through culture and language Multiple meanings, interpretations, realities Flux of processes, experiences, practices	Complex, rich, external 'Reality' is the practical consequences of ideas Flux of processes, experiences and practices
Epistemology	Epistemological relativism Knowledge historically situated and transient Facts are social constructions Historical causal explanation as contribution	Theories and concepts too simplistic Focus on narratives, stories, perceptions and interpretations New understandings and worldviews as contribution	Practical meaning of knowledge in specific contexts 'True' theories and knowledge are those that enable successful action Focus on problems, practices and relevance Problem solving and informed future practice as contribution
Axiology	Value-laden research Researcher acknowledges bias by world views, cultural experience and upbringing Researcher tries to minimise bias and errors Researcher is as objective as possible	Value-bound research Researchers are part of what is researched, subjective Researcher interpretations key to contribution Researcher reflexive	Value-driven research Research initiated and sustained by researcher's doubts and beliefs Researcher reflexive
Typical Methods	Retroductive, in-depth historically situated analysis of pre-existing structures and emerging agency Range of methods and data types to fit subject matter	Typically inductive. Small samples, in-depth investigations Qualitative methods of analysis, but a range of data can be interpreted	Following research problem and research question Range of methods: mixed, multiple, qualitative, quantitative, action research Emphasis on practical solutions and outcomes

Table 2.1 – Comparison of research philosophical positions, Source (Saunders, 2019)

Critical realism is a philosophy that "*focuses on explaining what we see and experience*" (Saunders, 2019) Pg 147. These observations or experiences are also known as empirical evidence. A critical realist will reflect on and analyse the empirical evidence to understand the reality of a condition, which is

autonomous to the empirical evidence. Knowledge for a critical realist is subject to a period in time with facts being social and cultural constructions rather than absolutes. In turn, these may cause biases to research and must be identified and addressed (Saunders, 2019).

Interpretivism is a philosophy that is rooted in social construct, focusing on the understanding of subjective matters rather than objective matters. As Myers (2019) puts it, the *"meanings in the human sciences are what constitute the facts*" Pg47. With each participant, there is a distinct perspective, experience and setting in which a researcher can find understanding. The output and contribution of the research is a byproduct of both the participants' inputs and the inherent inputs from the researcher's understandings (Saunders, 2019, Alharahsheh and Pius, 2020).

Pragmatism is "*the philosophy of common sense*" (Shields, 1998) Pg 197. It is a practical philosophy where the "*research starts with a problem,* and *aims to contribute practical solutions that inform future practice*" (Saunders, 2019) Pg 151. The research objectives likely derive from the practical problem and in turn, the contribution to knowledge is likely from the solution that promotes a successful output. The researcher's enquiry begins the process and the methods used can vary along the objective/subjective spectrum as the tools used depend on the nature of the problem (Elkjaer and Simpson, 2011, Saunders, 2019).

A pragmatism philosophy was implemented and appropriate throughout due to a number of reasons;

1- Ontology: The research should make an impact not just academically, but in practice. This is in line with question 20 from the HARP tool, a pragmatism based question stating "*The purpose of research is to solve problems and improve future practice*" Saunders and Bristow (2014) referenced in (Saunders, 2019) Pg 162. This in turn shaped the viewpoint to identifying a problem to solve. Ontologically speaking, between the 3 philosophies in Table 2.1, This viewpoint and reality is not layered between the empirical/actual/real and trying to understand the mechanisms between them, negating the application of a critical realism philosophy. The viewpoint in this case may hold some form of interpretivism as identifying the problem will require some form of input from participants and their realities. It will also have the researcher's interpretation of their

realities, but this is a subjective method rooted in achieving the wider goal of problem solving and practical contribution.

2- Epistemology: This research is motivated by a practical concern and the output of this research is to provide a solution to a problem identified in industry (AERA, 2006) referenced in (Randolph, 2007). Both subjective and objective knowledge is applicable to pragmatism as long as it serves in answering the research questions in a credible and reliable manner (Saunders et al., 2009, Saunders, 2019).

3- Axiology: The selection of a research problem was based on providing a solution to a practical problem. Research with a pragmatism philosophy heavily depends on and is driven by the values of the author. This means that there will be researcher bias (Saunders, 2019). The author values credibility in the research conducted and aims to achieve this by being as transparent as possible, identifying assumptions and noting the limitations of the methods implemented for the readers.

2.2. Approach to Theory Development

Saunders (2019) notes that there are 3 different approaches to theory development,

1- Deduction: Theory is developed through a literature review and the theory is tested via a research design.

2- Induction: The "*research starts by collecting data to explore a phenomenon and you generate or build theory*" (Saunders, 2019) Pg 153. Theory development can be presented in the form of conceptual framework.

3- Abduction: This is similar to induction but the theory is then tested through further data collection.

This research somewhat falls under an inductive theory development. Once the research objectives were set through the phenomenon identified in practice, data was collected through the synthesis of a systematic literature review with an assessment tool being the output and contribution of this research.

2.3. Methodological choice

The methodological choices that Saunders et al. (2009) refers to at this stage is defining whether the researcher will use qualitative or quantitative methods and defining how many methods will be used in the research. Quantitative methods lean towards objectivism, where the research data collection is measurable and follows scientific rigor to be fact-like. Qualitative methods lean toward subjectivism, where the data collection is subject to interpretation (Kelemen and Rumens, 2012, Saunders, 2019). The number of methods can vary depending on the research topic and can be a mixture of qualitative and quantitative methods. This research utilised multiple qualitative methods as the methods implemented were deemed appropriated based on the needs of the research objectives (Yin, 2009) (Schmidt, 2004).

2.4. Strategy

A research strategy is the approach that the author implements to select methods to answer the research objectives appropriately (Melnikovas, 2018). There is no correct strategy or method to solve the research objectives (Saunders, 2019). It is likely that different researchers would approach the same objectives in a different way based on their philosophical stances. Some may apply an objectivist approach with a scientific output and some may take a subjectivist approach with an interpretivist output. Accordingly, a research strategy was applied to solve the research objectives based on being transparent about the process.

As little information was found in literature on the management of lightweighting, even after four sessions with the faculty librarian to verify the literature review search design and application, an exploratory research strategy was applied. This strategy can be used to find relevant and appropriate problems in industry through interviewing practitioners, finding information in literature and focus group interviews (Saunders et al., 2009).

2.5. Time Horizon

There are two different type of time horizons that can be considered, a cross sectional time horizon, where the research is considered at one point in time, or a longitudinal time horizon, where the research is conducted over a period of time to compare data with the effect of time (Melnikovas, 2018, Saunders, 2019). This research considered a cross sectional time horizon by understanding the nature of a problem in industry at a point in time and providing a solution to it.

2.6. Techniques and Procedures

This final layer of the research onion is determining the techniques that will be used to collect data to answer the research objectives. These techniques are dependent on the prior selections within this chapter (Melnikovas, 2018, Saunders, 2019, Saunders et al., 2009). Within the scope of exploratory research, Saunders et al. (2009) refers to 2 methods that were used. Firstly, interviewing experienced practitioners and secondly, a search of the literature, but more specifically, a synthesis of the systematic literature review. The following 2 sections detail these methods respectively.

2.6.2. Preliminary Scoping interviews

Getting information directly from industry to identify a problem was the next step and Semi-Structured Interviews (SSI) with practitioners in industry was applied. This style was selected to provide organisational structure to the interview whilst allowing for the possibility of the conversation to evolve beyond the scope of the questions. This would prevent restricting the candidates to only answering predetermined questions, but collect data within the field in an exploratory manner and allow for the interviewer to identify avenues that may be out with the set questions (Denzin and Lincoln, 2005). The author also valued the face-to-face setting of the method as they would likely be more open to discussing issues than if a rigid, impersonal and objectivist method was used. This exploratory style of interviewing set out to achieve the following purposes,

1. Find potential research topics leading to research questions.
2. Contextualize my research and narrow research area of interest.
3. To find out how businesses are managing lightweighting. This includes but is not limited to perceptions of lightweighting, associated processes, challenges and other relevant discussions.

Chapter 4.2 details the scoping interview findings and analysis. The questions used and the Participant Information Sheet can be found in Appendix 1 and Appendix 2 respectively. The interviews were conducted in accordance to University of Strathclyde's ethical standards and the Participant's Information Sheet.

2.6.2.1. Strengths of Preliminary Scoping Interviews

SSIs were used instead of structured interviews because SSIs better supported the exploratory nature needed to identify possible current issues that a structured interview would not allow for if the opportunity arose. It would allow for experienced professionals to provide a more precise interpretation with personal experiences of the subject that may be out with the scope of questioning (Karlsson, 2009, Magaldi and Berler, 2020). It would also still be addressing the main points whilst allowing the opportunity for further probing (Gall et al., 1983).

An advantage of SSIs is that while the further questioning generally compliments the answers provided within the given structure, the answers provided differed in emphasis (Carruthers, 1990, Magaldi and Berler, 2020). This was noticed during these SSIs when industry issues and techniques were being discussed. A prime example of this was one of the candidates stressing that collaboration readiness of businesses in LW was a forefront issue with RCs and required immediate attention.

The questions were strategically selected and prioritised with respect to importance to accommodate busy or unenthusiastic participants. This helped in getting the main answers sought after first, but what helped build rapport was the ability to vary the order of questions asked and probe further based on candidate's responses, which allowed the conversation to flow more smoothly or naturally

(Magaldi and Berler, 2020). The author adapted to changes in each interview as they appeared and did not feel restricted with the rigor of a structured interview (Denzin and Lincoln, 2005).

2.6.2.2. Limitations of Preliminary Scoping Interviews

As these interviews were exploratory-based rather than confirmatory-based, that is, to find relevant problems in industry, the question regarding scope of candidates shifted from attaining a certain number to finding experienced candidates in industries that utilized LW that could provide current issues faced or tolerated. That is, they would be more likely to provide accurate and relevant scopes (Magaldi and Berler, 2020)(Denzin & Lincoln, 2005). Therefore, candidates were selected based on

1- Being in an industry that utilised LW
2- That had experience in the process of LW

Four candidates of various experience levels, working within industry and RCs were interviewed. A limitation to this small size can be the data collected might not necessarily be generalisable (Hackshaw, 2008).

Hove and Anda (2005) argued that the interviewer needed to be knowledgeable in the field prior to doing an SSI. It can be argued that some knowledgebase is required but not an in-depth one, as what is perceived from the emphasis the researchers put on it. It can also be argued for an exploratory-based SSI, some knowledge would be required to guide the conversation and develop the questions in accordance with the objectives, but the point is to let the experienced candidates share their knowledge, their insights and provide new information that can be reviewed afterwards.

Bogdan and Biklen (1982) referenced in Carruthers (1990) noted that a disadvantage to SSIs was that some control would be handed to the candidate when going beyond the interview questions, allowing for the possibility of the conversation to side track. This issue was noted to occur in the first interview, where the candidate did side track a few times, requiring the conversation to be brought back on track without cutting off the candidate and dissuading them from sharing further. This was a difficult

challenge; however, this was countered by selecting opportune times to speak, acknowledge what the candidate said to maintain rapport and bring them back by discussing the next question.

Another limitation or possible risk when interviewing candidates was that they may boast or exaggerate their responses or be reserved due to the fear of backlash from their employers, peers or colleagues. This was addressed when it occurred through applying the recommendations of Bugher (1980) referenced in Carruthers (1990). That is, it was evidentially proven that candidates were highly likely to provide honest and forthright views in face-to-face interviews when the candidate was aware of the interview purpose, anonymity was ensured and the questions were articulated coherently, all points that were applied. It was noticed that the only reservation that candidates did have was not breaching confidentiality, an ethical prerequisite for these interviews, and they occasionally paused for moments to carefully word responses to satisfy these requirements.
It is acknowledged that SSIs are more likely to have the interviewer's influence than structured interviews due to the interviewer probing further (Denzin and Lincoln, 2005, Karlsson, 2009). However, the SSI style supports the scope requirements. Although bias is expected through the need for finding relevant issues, it is aimed to be lowered through maintaining neutrality and by steering clear of sharing views on the topic whilst adhering to ethical guidelines (Karlsson, 2009, Denzin and Lincoln, 2005, Magaldi and Berler, 2020).

A lesson learnt is that many off-record conversations had taken place with professionals in industry, but this doesn't hold up for it to be accepted to the high level, peer-review standard of academia. Since there was little information available on the topic in literature, it would have benefited this research to capture many of these conversations and critically review them.

2.6.2. Synthesis of a Systematic Literature Review

Once the problem was identified in practice and in turn became a research objective, a solution was sought for it. This was done through a synthesis of a systematic literature review. The purposes for doing this method were,

1- Identify a gap in knowledge and establish a valid contribution that this research can deliver: This is addressed through the review of literature at the intersection of the different subject

areas of the objectives and confirm a gap in the knowledge that a contribution can be made to (Easterby-Smith et al., 2008) (Denyer and Tranfield, 2009).

2- Provide relevant key literature (Easterby-Smith et al., 2008): This is addressed through identifying how other researchers approached a similar problem, learn from how they addressed it and use appropriate details that were translatable and applicable to this research.

The details of the systematic literature review can be found at the beginning of Chapter 5.

2.6.1.1. Strengths of a Systematic Literature Review Synthesis

There are numerous strengths to applying a Systematic Literature Review (SLR). Such as reducing bias and error through a scientifically rigorous review that is transparent and auditable in process, decision making and assumptions made with ease of replicability (Dissemination, 2001) referenced in (Denyer and Tranfield, 2009) and (Yin, 2009, Easterby-Smith, 2012, Gummesson, 2000). It helps refine literature to that which is highly relevant in a reasonable number of studies (Easterby-Smith et al., 2008). Gaps in research can be more confidently identified with added validity to researcher contribution to knowledge with output that can be utilised in practice, disseminating knowledge and identifying future research avenues (Easterby-Smith et al., 2008, Denyer and Tranfield, 2009).

Applying an SLR provides structure to finding literature with a defined scope to work with at the end. The SLR design was verified by the Faculty Librarian adding to the confidence in the design and application. This process provided a reasonable number of studies to work with. When the data was synthesized and critically reviewed, a gap in knowledge was identified with the contributions that could be made. The demanding process provided a contribution to academic rigor. Such as, the development in achieving a critical awareness of finding relevant literature through targeted questioning, boundaries, decision making processes, filtering, key selections, analysis and synthesis.

2.6.1.2. Limitations of a Systematic Literature Review Synthesis

The scope of the SLR is restricted by what the author selects. Three methods were used in this selection. Firstly, was to plan and ensure a strong understanding of what is expected in each stage prior to conducting the SLR. This was done through reviewing seminal work on SLRs. Secondly, the SLR was constructed in adherence to guides in literature. Thirdly, the Faculty Librarian was asked to verify the SLR construction.

The SLR can also be said to restrict relevant papers that fall out-with the defined scope. This was addressed by looking through as many relevant peer reviewed search engines that could be reasonably used in the given time limit and through cross-referencing highly relevant or seminal papers.

During the SLR, multiple searches were conducted for various ways of assessing innovation readiness in literature, such as maturity, capability, readiness or matchmaking. This was to provide a comprehensive review on the subject. While they are very similar, each niche is subjective to their own context and the author's used terminologies. The research focus was specific to partner selection, compatibility and identifying a readiness of businesses during the enquiry stages. To account for these differences, an analysis and combination of terms under similar brackets were used, allowing for the application and consideration of data to the research context to be comprehensive and targeted.

The synthesis of the literature review is subjective to the author's interpretations of what is applicable to solution of the research objectives. While this in itself is not a limitation, the author wants to acknowledge this.

Another possible critique of this work is that the LW presented is predominantly from an engineering design perspective. This is somewhat true. LW is deeply rooted in the design process and stems from design thinking, which can be seen from the frameworks presented in Table 3.2.

2.7. Summary of Research Philosophy and Design

Table 2.2 below provides a summary of the research philosophy and design implemented in the research.

Criteria	Selection
Philosophy	Pragmatism
Approach to Theory Development	Induction
Methodological Choices	Multi Method Qualitative
Strategies	Exploratory
Time Horizon	Cross Sectional
Techniques and Procedures	Preliminary Scoping Interviews Synthesis of Systematic Literature Review

Table 2.2 – Summary of Research Philosophy and Design

Chapter 3

Lightweighting – A Review of the Context

3. Lightweighting – A Review of the Context

Chapter Purpose	To detail key points to develop a theoretical understanding of the management of lightweighting, including identifying key attributes and frameworks used that can provide context for the assessment tool. This chapter is deliberately put at this stage to provide a baseline understanding prior to other chapters which reference different aspects of lightweighting.
Chapter Output	This chapter directly addresses the first research objective by identifying the management aspects of LW, it's components, influential factors and the frameworks used.

"When you have exhausted all possibilities, remember this - you haven't." - Thomas Edison

There is a general agreement in literature that lightweighting is the intentional design of a component or product to become lighter than it initially was or would be using standard methods, in order to perform a required task (Tempelman, 2014, Zhu et al., 2018, Fan and Njuguna, 2016). Researchers in this field point out that the design is tailored and optimised for a unique application (Kaspar and Vielhaber, 2016). In many cases, the design is made as light as possible within the given boundary conditions, such as, in order to meet allocated funding, required timescales or potential geometrical constraints (Hottle et al., 2017, Wu et al., 2017).

Lightweighting (LW) has been, and continues to be, a vital concept in the design and manufacture of aircraft components since the industry's establishment (Tempelman, 2014, Kaspar and Vielhaber, 2016). With increased policies for both a reduction in carbon emissions globally and reduced fuel consumption in addition to the need for lighter more efficient aircraft components, there has been a

growing interest in both academia and industry to incorporate lightweighting techniques throughout the manufacturing process. With the benefits that it provides, other industries have adopted lightweighting techniques (Marino and Sabatini, 2014).

There was an investigation of different, albeit limited, theoretical frameworks related to lightweight manufacturing. This was mainly done by examining textbooks, journal papers as well as employing a structured literature review approach (Randolph, 2007). Interestingly, most of the journal papers on lightweighting tended to be technical, with few that appeared to address the management of lightweighting and associated innovation processes. This is likely due to the predominance of lightweighting in the design room and potentially indicates a gap of the lightweighting concept within manufacturing and management literature. Consequently, the review was extended to include technical journals to gain an understanding of lightweighting and its application. Search engines ProQuest and Compendex were primarily used for gathering data on lightweighting. Furthermore, cross-citations were relied upon and preliminary scoping interviews were used to identify key issues faced by businesses in lightweighting. And finally, other sources were considered through a conventional literature search in attempts to identify relevant material that could have been missed through a structured literature review.

The following sections will explore lightweighting in the literature and identify attributes translatable to metrics to successfully measure lightweighting. This will be used in the development of a theoretical assessment tool in the following chapter.

3.1. The Purposes and Drivers of Lightweighting

As identified in Section 1.1, lightweighting is a fundamental concept applied more notably in vehicle and aircraft engineering, primarily due to the key functionality that weight has during operation, though, its implementation can possibly prove beneficial to a variety of applications. Furthermore, there have been customers pushing for cheaper low carbon footprint vehicles, and initiatives by regulatory authorities and other bodies that has contributed the introduction of lightweighting to

other industries and subsequently businesses. In a careful review of literature, most reasons for lightweighting tend to be for one or more of three purposes, functionality, sustainability and profitability, which will be discussed below (Zhu et al., 2018, Fan and Njuguna, 2016, Czerwinski, 2021). These three purposes are generally interconnected and usually mean two or more are simultaneously achieved in the process, whether or not it was intentional to do so.

3.1.1. Functionality

Firstly, functionality is a key component in lightweighting that drives its use in various applications. It involves an exercise that questions the necessity of each component and strictly reducing components in size and number to meet the requirements for functionality reliably (Tempelman, 2014, Herrmann et al., 2018). It questions the design, manufacturing and material selection processes to investigate innovative and streamlined methods to reduce weight. The reduction in weight translates into less forces acting upon the design and less energy or resources required for its operation (Marino and Sabatini, 2014). This allows for the possibility in increasing the scope of design features and parameters. These parameters can be increasing payload, improving performance such as range and duration, improved functionality, easier logistical handling, attaining efficiencies such as fuel and energy consumption, a reduction in stresses and fatigue which consequently gives way to the possibility of a longer design life and the list goes on (Herrmann et al., 2018, Zhu et al., 2018, Gesrepair, 2017, Crosse, 2009, Brooker et al., 2013, Fan and Njuguna, 2016).

Perhaps one of the greatest advantages of lightweighting is the cyclical gains in functionalities from the initial weight reduction, illustrated in Figure 3.1 (Herrmann et al., 2018, Hottle et al., 2017, Luedeke et al., 2014b). That is, when an initial weight reduction is applied, the forces acting upon the product are reduced. This means that the amount of energy and resources required to operate the newly weight reduced product have decreased causing a reduced shift in design requirements from the initial parameters, making scope for further weight reductions and increasing financial gains. Similarly, in large products consisting of assemblies of many components, the weight reduction of one of the components can cause a knock-on effect in weight reduction of the other interdependent components creating a new cycle weight reduction (Herrmann et al., 2018, Hottle et al., 2017, Mallick, 2010, Zhang et al., 2020, Luedeke et al., 2014b).

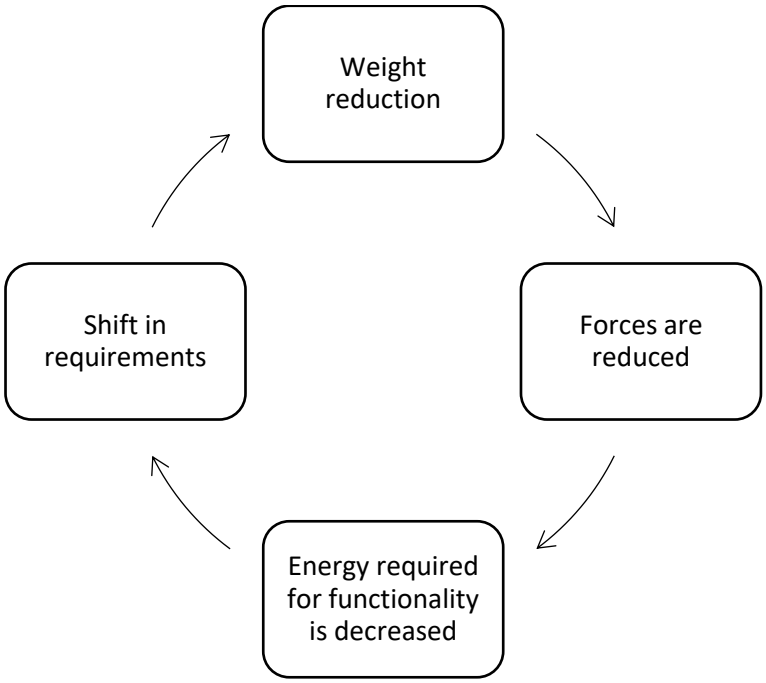

Figure 3.1. Cyclic Gains in Functionalities

3.1.2. Sustainability

The most noted in literature, and certainly a popular driver stated in almost every paper reviewed on lightweighting, is sustainability. With reducing greenhouse gas emissions being a key criteria for design in today's engineering, there is a growing responsibility upon businesses for their products to have a lower impact on the environment, throughout a products lifecycle (Mouritz, 2012, Gesrepair, 2017). Many Original Equipment Manufacturers (OEMs) within the automotive industry have identified sustainability as a driver for lightweighting (Pervaiz et al., 2016). Regulatory bodies are implementing emissions targets for businesses to achieve, whether that be in manufacturing or in product operations. For example, the International Civil Aviation Organisation (ICAO) has set a target to reduce 50% of aviation related emissions by the year 2050 (Marino and Sabatini, 2014) referenced in (Zhu et al., 2018). Similarly, the UK Climate Change Act 2019 stated a reduction target for the net UK carbon account of at least 100% in comparison to the baseline levels in 1990 (Priestley et al., 2019). Some of these authorities, including the UK Government are imposing carbon emissions tax upon

manufacturers and industrial premises and it will not be a surprise if these taxes increase significantly closer to 2050 (Government, 2020).

With the popular and substantiated trend in sustainability amongst manufacturing, operators and customers, any development by businesses throughout the supply chain in optimizing or streamlining their products and processes is highly welcomed, encouraged and could be used in marketing (Fan and Njuguna, 2016). Researchers, such as Marino and Sabatini (2014) agree that lightweighting is directly linked with sustainability and the reduction of carbon emissions, which is why it is a key driver in the context of lightweighting. From the identification of sustainability and lightweighting has emerged lightweighting lifecycle analyses, an advanced comprehensive technique to identify the benefits of lightweighting a product throughout its lifecycle, that is, from idea concept to end of life and recycling. This will be discussed in more detail in Section 3.3.

3.1.3. Profitability

Finally, profitability is mentioned frequently throughout literature as a key driver for lightweighting (Zhu et al., 2018, Gesrepair, 2017, Montalbo et al., 2009). Reducing costs will always be a driver for businesses as is commonly expected (Howe, 1909) and it can be reasonably assumed that the majority of lightweighting applications will be to some degree profitable or cost neutral. Though, lightweighting will always be associated with cost as it is generally perceived as being costly. Though in some scenarios, it is not always profitable to lightweight, even although the outcome might be more sustainable and the same could be said vice versa (Witik et al., 2011). Herein lies the dilemma and challenge faced by businesses between sustainability and profitability. Through the imposing of sustainability targets and carbon tax emissions by regulatory authorities, businesses will no doubt need to adhere to the targets at some point. This will require businesses to identify innovative solutions in their processes and products to be both sustainable and profitable. This balance could gain businesses an advantage in the present market and could likely be a requirement to survive in the future, and lightweighting is a key principle that should be considered when discussing these topics (Molnar, 2014).

3.1.4. Other Purposes and Drivers

In addition to the three key drivers mentioned above, there are other aspects that drive lightweighting, such as improved quality and resilience (MacDougall, 2018), quality innovative research (Kleiner et al., 2003) and the challenge for radical new designs (Tempelman, 2014) (Kaspar and Vielhaber, 2016). However, it must be noted that the purpose and application of lightweighting should be closely monitored against the drivers as a lack of doing so may cause adverse effects (Witik et al., 2011). It is an accepted best practice that drivers and purposes be translated into measurable outcomes to determine the degree of success in the use of lightweighting. These metrics will be discussed in further detail in Section 3.4.

3.2. Unique Attributes of Lightweighting

The implementation of the lightweighting principle can affect everything downstream from idea generation to end of life (Herrmann et al., 2018). However, within literature, there are generally recurring engineering disciplines referred to and given importance by authors when lightweighting. They can be considered as direct influential factors and therefore must be considered when lightweighting. Three of these components, considered to be the key pillars of lightweighting, are design optimisations, material selections, and manufacturing processes (Herrmann et al., 2018, Tempelman, 2014, Zhu et al., 2018). These aspects are all interlinked and need to be considered with respect to one another throughout the process where possible (Tempelman, 2014, Kaspar and Vielhaber, 2016). But prior to these aspects being elaborated upon further below, there is another aspect, which is not discussed directly in literature though appears frequently are intentions. This could possibly be argued as designing for purpose, and not over-specifying (Tempelman, 2014), which it is. The intentions are generally mentioned at the beginning in literature and then the impacts that lightweighting had on the drivers are discussed at the end. With this recurrence in literature (Lewis et al., 2014, Sewell et al., 2016, Ishak et al., 2018, Mallick, 2010), it is important to identify intentions to make something lighter.

3.2.1. Lightweighting Intentions

Typically, lightweighting is an iterative design process in which there is a previous design that someone wants to make lighter for a beneficial reason (Tempelman, 2014, Zhu et al., 2018, Roy et al., 2008). The intention is usually one or more of the drivers mentioned within Section 3.1. However, considering sustainability as a driver, Witik et al. (2011) and Herrmann et al.(2018) note that the implementation of lightweighting does not necessarily equate to a reduction in environmental impact, but can have the opposite effect. This could be through the number of emissions required to build the product or source the necessary materials are far greater than the lifetime assessment of emissions that the newly weight-reduced product would produce. Furthermore, as Mouritz (2012) points out, the current trend for material selection is revolving around reducing greenhouse gas emissions. This reduction is also a driver for lightweighting and can be correlated to it, with many papers in the last decade concerned with lightweighting refer to the reduction of greenhouse gas emissions of carbon emissions as a cause (Pervaiz et al., 2016, Allwood et al., 2010, Isenstadt et al., 2016, Luk et al., 2018). Therefore, it is important to identify the intention to lightweight and assess the impact accordingly as the process begins with this. It gives those involved an objective to work towards (Kaspar and Vielhaber, 2016). For example, if the driver is to reduce cost, then it is fair to assume that there will be an assessment of cost as part of the weight reduction process. However, if the driver, for example, is to reduce greenhouse gas emissions, then it would be fair to assume that there will be a comparison in lifecycle assessments of the product before and after lightweighting, with the selection of the most appropriate design. The above demonstrate the importance of identifying the intentions of lightweighting at the start with their associated metrics.

3.2.2. Pillar 1 - Design Optimisation

Lightweighting is generally conducted through two avenues, the reduction of materials or components necessary for functionality, and the use of different materials with lower densities (Herrmann et al., 2018, Tempelman, 2014, Zhu et al., 2018). Both are usually conducted at the planning and design stages in which a product would be developed and potentially optimised for purpose. Design

optimisation in lightweighting is best described by Tempelman (2014) as designers striving "*… to ensure that the product does exactly what it needs to do, and nothing more*" Pg. 249. This entails identifying key requirements and designing to meet the criteria in the simplest form possible, achieving an efficiency, functionality and safety in design (Le Duigou et al., 2016, Beyer, 2014). With significant technological developments in design optimisation tools, designers and engineers are able to model, simulate and test products virtually, a practice which is now considered essential for any serious engineering-based businesses (Roy et al., 2008, Le Duigou et al., 2016). Research advancements in the use of conventional design optimisation tools have developed to utilise components in size, shape and topology (Bendsøe, 2004, Zhu et al., 2018). That is, identifying the component performance or other requirements and iteratively adjusting the component to be more utilised than originally whilst safely perform its function (Rao, 2012, Le Duigou et al., 2016, Taub and Luo, 2015). In the case for lightweighting, this is utilised for weight reduction. An example of this is the widely renowned Airbus A350 XWB titanium 3D printed bracket that was heavily optimised topologically, which demonstrated the potential capabilities of design optimisation tools, where the original product is optimised to have a lower volume of material, and subsequently, a lower weight. It does need to be mentioned that these advancements in design optimisations generally require special training.

An important caveat discussed by authors is that design optimisations must consider the materials that are going to be used and the manufacturing processes to build it, as materials respond differently and the product might not be able to be manufactured, or be very costly to do so (Tempelman, 2014, Herrmann et al., 2018). This leads some authors referring to the lightweighting process as a holistic process, in which the design, manufacturing and materials of a product are closely interconnected, as they depend on one another for the possibility of successful designs (Kaspar and Vielhaber, 2016). As Zhu et al. (2018) puts it, "*A typical approach to achieve lightweight design for aerospace components and systems is to apply advanced lightweight materials on numerically optimised structures, which can be fabricated with appropriate manufacturing methods*" Pg 104. While this is important in and arguable applicable to any industry, for a research context, this raises the possibility of hindering innovative methods in which to develop further in each engineering discipline. For example, if a

researcher seeking for a new innovative design is not restricted by available manufacturing methods, and posts the findings in a journal, this could inspire another researcher to develop a manufacturing method that could potentially create further opportunities. Though, the researcher is aware that this is not suitable for project-based environments, rather, the research and development field.

3.2.3. Pillar 2 – Materials Selection

Considered a significant contributor to innovation, material development and selection play a large role in lightweighting (Eerola et al., 2015). Aluminium alloys and a mix of low carbon steels and high strength steels have generally been the reference materials used in the aviation and automotive industries respectively (Dursun and Soutis, 2014, Mallick, 2010, Zhu et al., 2018). However, due to the growing requirement for gaining an edge on competition, lower greenhouse gas emissions and subsequently weight reduction in vehicles, there has been a greater focus on materials, including the development of new materials, utilising current materials, joining materials, and material substitution. Each of these techniques can prove beneficial for lightweighting if they are applied correctly to the appropriate situation. Materials selection plays an important role in lightweighting and due diligence is required in the process of selection. With the holistic nature of lightweighting already identified, the selection of materials for each application should not be independent of designing and available manufacturing unless for one identified specific reason (Mouritz, 2012, James, 2016, Tempelman, 2014, Kaspar et al., 2018, Mallick, 2010).

3.2.3.1. Utilising Current Materials

There are a number of advanced materials that have been gaining momentum in lightweighting, with research developments in the fields of composites and alloys, such as titanium, aluminium and magnesium (Mallick, 2010, Herrmann et al., 2018). However, this does not limit lightweighting exclusively to advanced materials. One observation noted is that some regulatory bodies and authors associate lightweighting to advanced materials, giving the impression that lightweighting is the use of advanced materials only or associated manufacturing processes. Perhaps this is due to them looking

at the forefront and of technological developments in materials and considering scope for potential advancements. Tempelman (2014) shares a similar line of thought and points to the use of common materials, such as steel and bamboo, and goes further to address that one should not limit lightweighting to light materials and composites, but be open to other possibilities, including steel. This leads to the thought that with current designs under lightweighting consideration, the substitution of materials should not be directly assumed and the utilisation of current materials should be considered within the lightweighting process through design optimisation (Taub and Luo, 2015, Government, 2018, Mallick, 2010).

3.2.3.2. Material Substitution

A common method for lightweighting is substituting materials. The use of lighter materials with similar or greater certain material properties than the original can prove to be beneficial, and is a leading aspect in literature (Herrmann et al., 2018). Zhu et al. (2018), referring to Dursun and Soutis (2014), Flower (2012) and Peters and Leyens (2009) indicated that research in the use of lighter materials was the most effective method to improving structural efficiency. Materials such as high strength steels, aluminium alloys, titanium alloys and composites have presented great advancements and potentials for the purposes of lightweighting (Zhu et al., 2018, Herrmann et al., 2018). There are various contributing factors to selecting a material. It is important to identify what are the drivers to selecting one material over the other. There are a few aspects which must be accounted for when considering other materials besides the criteria of mechanical properties. Firstly, in highly regulated industries, such as the aviation industry is commonly renown for, some materials are not approved for operational service by regulatory authorities, requiring a stringent testing and verification process before approval (Cooper et al., 2017). This potentially discounts many viable substitutions from consideration in the immediate. Secondly, there must be a consideration for manufacturability of the material for its application (Dursun and Soutis, 2014). Some materials are unsuitable for an application due to the limited manufacturing capabilities for the required design shape or configuration (Tempelman, 2014). Thirdly, some materials may be rare, cannot be recycled or require a lot of energy to produce, negatively impacting the environment (Prendeville et al., 2014). So, if sustainability is a key driver, then considering the life cycle of the selected materials would be pertinent.

3.2.3.3. The Development of New Materials

A key research forefront in lightweighting literature is the development of new materials. Researching new materials generally present advancements in one or more characteristics or properties, including lower weight, better lightweighting material properties (strength, stiffness, elastic modulus, etc.), better performances (for example, under certain mechanical conditions such as bending and torsion), manufactured through a certain method with a reliable output, more easily manufactured, environmentally sustainable, recyclable, made with readily available materials, improved life cycle analysis, cost effectiveness and the list goes on (Herrmann et al., 2018, Tempelman, 2014). Such advancements could potentially prove highly beneficial in reducing timescales, costs, environmental impacts and improving functionality. These advancements in lightweighting materials development have been primarily noted within titanium alloys, aluminium alloys, magnesium alloys, high strength steels, composites and hybrid materials. Moreover, some of these developments can be made tailor specific for unique applications, such as certain composites and hybrid materials (Mallick, 2010).

The development of new materials should be encouraged for advancements in technology or to attain a competitive or leading advantage. Within lightweighting RCs and relevant businesses, it would be expected that some form of this research is being conducted. For this research, it seems pertinent to identify the intentions for a business to lightweight, identify and implement associated processes to achieve the necessary outcome (Pervaiz et al., 2016, Dursun and Soutis, 2014, Le Duigou et al., 2016). For businesses seeking to collaborate in lightweighting with RCs, unless the development of a new material is not the determined objective, the question then raised is have collaborative efforts exhausted other possible opportunities through utilizing current materials and considered other existing materials? what would they hope to gain from developing a new material? Are there certain characteristics that they are trying to improve?

Hybrid and composite materials are seen to be opportunities where developments therein can provide tailored outputs. The majority of businesses that are implement lightweighting using metals rather than hybrids and composites (MacDougall, 2018). This is most likely due to one of three things, businesses working within their own remits and creating advancements, businesses identifying advanced materials are not the answer or it presents an issue of lack of skills in advanced materials by

designers. The second option, while it is a valid point stated by Tempelman (2014), this is less likely to be in the majority of businesses, most likely due to the lack of skills in identifying and use of more advanced materials. Furthermore, the process chain development may require changes, a point which would be difficult to get senior management support for.

3.2.4. Pillar 3 - Manufacturing Processes

The manufacturing process can be considered the pillar that puts to realisation generated concepts in the earlier stages of product lifecycle, more specifically, the design optimisation and materials selection stages. Manufacturing processes can be viewed as an influential factor to the development of a lightweight product and can be considered a "go/no-go" decision maker for the processes of project related products, commonly referred to as manufacturability. This is because the design is dependent on the ability to manufacture the product (Zhu et al., 2018, Roy et al., 2008).

Similar to materials selection, there are different methods of manufacturing and an approaching business seeking support in manufacturing methods that tend to fall under three main brackets, optimizing and utilizing current methods, the use of newer methods and the development of new methods. There is a vast amount of manufacturing methods, both current, new and in development that it does not serve the purpose and it out with the scope of this research to discuss all of them and find metrics for each method. To address this, common denominators were identified that transcends variations between manufacturing processes to successfully assess their contributions towards lightweighting, their use within businesses and the boundaries of their application in collaborations (Kaspar and Vielhaber, 2016, Herrmann et al., 2018, Zhu et al., 2018).

Each product has its own design, assembly of components, materials and finishes. To attain the final product, the materials need to go through a manufacturing process, likely consisting of various manufacturing methods being applied at different stages. A change in the design or materials used can cause multiple changes downstream. Requiring such changes could be due a number of reasons, such as business objectives, internal R&D or clients demanding improved performance parameters. Businesses may approach and RC requesting that their current manufacturing methods be utilized or optimized further. This would be in the form of increasing efficiencies and reducing costs in the current

setup, through methods such as reducing the amount of material wasted, achieving better target productions, reducing the rate reworks, improving tolerances or even defining new metrics to achieving a more profitable outcome, time-saving process or quality of product (Lewis et al., 2019, AFRC, 2021, Roy et al., 2008).

The use of newer manufacturing methods is the implementation of established methods or processes that have been qualified for operations, that is, on the higher end of the TRL scale. Businesses could introduce new manufacturing methods if there have been significant or innovative changes to a product design, new materials being used, a new product being introduced or for investing and updating methods for improved production qualities, timescales and costs. With the introduction of a new manufacturing method are new associated processes and procedures and skills required to name a few. Such changes are sometimes noted in literature to be structured in the manner of a manufacturing or engineering change management, where processes and production are scrutinized to identify relevant parameters and provide the management of manufacturing changes that are in an effective and efficient to the requirements of the business. The development of new manufacturing methods would be the process of establishing of a manufacturing setup to achieve an old or new design but that has not yet been qualified for operations, that is, lower to mid ranges of the TRL scale (Koch et al., 2016, Roy et al., 2008, Nordin et al., 2012, Sippl et al., 2022).

There are various different types of manufacturing methods and processes at different TRL stages. There were two key manufacturing themes highly relevant to lightweighting that was mentioned throughout literature. The first manufacturing method was multi-material joining. Implied in the name, multi-material joining is combining two or more different materials together through a combination technique. This is usually done to optimize the use of materials in an assembly and in turn reduce the weight. For example, a car chassis might be made of different materials as different parts of it undergo different forces. Due to the varying properties of the materials being combined, various methods of joining them together are being used to ensure compatibility, longevity, reliability during production and suitability for operations. There are also new methods at varying TRL levels being researched and introduced accordingly. Joining can be done through various methods, the materials can be joined mechanically, thermally, adhesively and through hybrid methods, which could

be a mix of other joining technologies (Kim et al., 2019, Taub and Luo, 2015, Meschut et al., 2014, Kaspar and Vielhaber, 2016).

The second manufacturing method is additive manufacturing. With advancements in optimising topologies of components and the possible opportunities that come with it, additive manufacturing, or what is generally known as 3D printing, is seen to be a viable method to achieving manufacturing complex topologies. There is a research focus of interest in this as researchers aim to build optimised technologies with a preferred material or multiple materials joined together. Seen as the oppositive of subtractive manufacturing, that is, the removal of material to the design shape and form, additive manufacturing is the building of a component through material/s usually being laid upon one another to a design that has been engineered and computer-modelled. Additive manufacturing is seen to be a possible manufacturing method that may revolutionise industries, supply chains and the process of making components as and when. Furthermore, it is seen as more environmentally friendly than subtractive manufacturing as there is a signification reduction of waste and providing the opportunity to build components with less material, resulting in a lower carbon impact (Beyer, 2014, Li et al., 2016).

3.3. Types of Lightweighting

There are different lightweighting styles identified both in literature and in the preliminary-scoping interviews. Below discusses and compares different types of styles.

3.3.1. Holistic vs. Specific Lightweighting

There are a multitude of articles on lightweighting provided the application of weight reduction to a specific component or small assembly. In many cases, the weight reduction was conducted through one of the three pillars of lightweighting, namely, design optimisation, material substitution or applying a new manufacturing process. The research articles seemed to be specialised in their respective areas and applying the concept of lightweighting. This method is considered to be specific lightweighting, where the focus is on applying one pillar of lightweighting and analysing the effects of such changes with respect to weight reduction.

A holistic approach views lightweighting as a process and considers the effects and interactions a change to one of the pillars of lightweighting will have on the others. For example, the change in a material could require a change in the design and the application of a different manufacturing or processing method (Kaspar et al., 2018).

3.3.2. Direct vs. Indirect Lightweighting

During preliminary scoping interviews, an indirect method of lightweighting was identified after discussion with one of the interview candidates (Candidate C). The candidate, who worked in the aviation industry, mentioned two times when weight was of particular interest to the business. Firstly, at the initial stages of an aircraft design, lightweighting is considered one of the main priorities due to the significant advantages already discussed in Section 3.1. The freedom and ability to make changes at the start to components and assemblies is much easier than at a later stage when the design has been completed and is operational. Lightweighting under these circumstances is conducted in a direct and linear manner, where the intention is to reduce the weight.

The second time when weight is of interest is when modifications of components are required after the overall design has been completed and is operational. The timing in modifications imposes additional constraints because changes in weight could have a knock-on effect to adjacent components and subsequently the overall design, potentially requiring time-consuming additional analyses and re-designs. To prevent this knock-on effect and limit the changes, designers make modifications but closely monitor weight to maintain neutrality between the original and new designs.

Candidate C did not identify this neutral weight designing as lightweighting since no weight was actually reduced. However, on reflection, this can be argued to be an indirect form of lightweighting. All the unique attributes of lightweighting are considered in this scenario by the designers, however the only identified change is in the intention, where instead of reducing the weight for its advantages, the constraints preventing further weight reductions, for logical reasons, creates the next possible alternative, which is to maintain the same weight. Within this close monitoring of weight, the modifications will likely create a weight offset initially, in which the designers will then actively work

to obtain the original weight. So instead of looking at the goal post in terms of reducing weight as much as possible, the target weight is set as the original weight design. See Figure 3.2 below. Any modifications that are made by designers is likely followed by an iterative process to achieving the target weight, utilize lightweighting processes to either increase or decrease the weight. Thus, the term indirect lightweighting, as the intentions deviate from standard lightweighting found in literature. In some cases, this could be significantly harder than direct lightweighting due to the additional constraints. Interestingly, another preliminary interview candidate (Candidate D), also within the aviation industry, confirmed the implementation of indirect lightweighting similar to the other candidate, though, didn't attribute it to lightweighting or any method, other than weight neutrality.

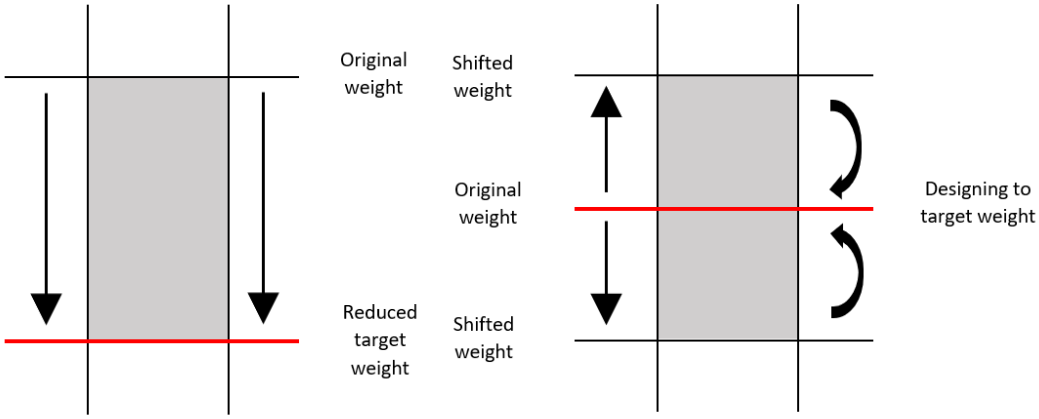

Figure 3.2. Direct vs. Indirect Lightweighting

In Figure 3.2, for direct lightweighting (left), you have the original weight being reduced as low as possible to the target weight. For indirect lightweighting (right), the red line represents the original weight and the target weight to which the deviations must return to, whether these weight deviations are over or under the target weight.

3.3.3. Life Cycle Assessment

Life Cycle Assessment (LCA) is an extensive evaluation of the life cycle a product or component goes through. In this assessment, all stages and activities of a product or component are considered, from the extraction of raw materials, to transportation, production, operation and finally end of life or recycling/reusing. This allows for a holistic overview and consideration of environmental and energy impact that a product or component has and requires to fulfil its purpose. For example, climate ozone and health impacts as well as the use of resources (BSI, 2006, Herrmann et al., 2018, Karakoyun et al., 2014).

LCA is a prevalent topic in field of lightweighting with many authors applying it to various products, components and assemblies. It is important and relevant to the field since one of the key drivers for implementing lightweighting is sustainability and the reduced impact that a lighter product can potentially have on the environment and resources (Del Pero et al., 2017). This is particularly significant to this research as some candidates have identified the need to justify implementing lightweighting, pointing out that reducing the weight of a product does not necessarily equate to being more sustainable, as the life cycle impact of lighter product may in fact be more detrimental to the environment and use of resources than a heavier product (Herrmann et al., 2018). For this reason, if sustainability is the key driver or is being considered, then LCA must be also considered alongside other driving factors, targets and boundaries, such as costs, performances or legislation.

LCA does prove to have significant advantages in its implementation. It provides a holistic understanding of a system, developing insights into products and processes. It helps identify processes or areas that are inefficient, allow for potential trade-offs between areas, and gives information to help users find more sustainable ways to manage products and their processes (Herrmann et al., 2018, BSI, 2006).

3.3.4. Influential factors to Lightweighting

This section identifies influential factors to lightweighting. These factors are important to consider because they are potential variables that may impact the outcomes of collaborations between RCs and businesses in lightweighting. These influential factors, when harnessed positively open up opportunities and if mismanaged can stifle progress. Table 3.1 below lists key influential factors.

Section	Influential factors	Possible impact (generally, not exclusively)	Reference
3.1.R1	Cost	Cost is a boundary that limits the degree of lightweighting applied. Businesses will generally have allocated a budget and will work to a certain point of investment.	(Mallick, 2010) (Zhu et al., 2018) (Gesrepair, 2017)
3.1.R2	Time	Lightweighting can be a timely and iterative endeavour for training and implementing advanced techniques, both on screen and in practice. Furthermore, changes upstream can affect things downstream and changes have to be made throughout.	(Mallick, 2010) (Gesrepair, 2017)
3.1.R3	Performance	The achievement of a certain quality or performance of a product can drive the use of lightweighting.	(Gesrepair, 2017) (Zhu et al., 2018) (Herrmann et al., 2018) (Crosse, 2009)
3.1.R4	Manufacturability	The design must be able to be manufactured with the respective materials. Sometimes this may halt concepts going forward, but it may also hinder timelines if the lack of manufacturing processes is available on site. On the other side, some manufacturing techniques can enable lightweighting, such as additive manufacturing.	(Roy et al., 2008) (Zhu et al., 2018)
3.1.R5	Available Technologies	The use of design optimisation tools can allow for optimized and utilised designs, as much as the manufacturing technologies can accommodate.	(Zhu et al., 2018) (Tempelman, 2014) (Le Duigou et al., 2016)
3.1.R6	Materials used	The use of some materials and manufacturing processes can require additional training, due to the non-uniform behaving characteristics, such as composites, a popular LW material avenue.	(Mallick, 2010)
3.1.R7	Skills and training and familiarity	Lightweighting sometimes involves high level design optimization and working with various materials and composites. These two points require extensive training to work with as it requires new strategies and methodologies to be used.	(Mallick, 2010) (Gesrepair, 2017)

3.1.R8	Regulatory Standards and Testing	As safety is a priority, regulatory standards to achieve a new design being implemented are stringent, with significant testing being applied. To achieve standards due to changes may prove difficult.	(Herrmann et al., 2018) (Gesrepair, 2017)
3.1.R9	Set ways	Senior Management and businesses may be set in their ways, referring to the extensively used tried and tested methods.	(Gesrepair, 2017)
3.1.R10	Sustainability and Environmental impact	A big driver for LW, Governments are pressing industries to have lower environmental impacts.	(Government, 2020) (Fan and Njuguna, 2016) (Marino and Sabatini, 2014) (Zhu et al., 2018)
3.1.R11	Customer Influence	Customers pressing for environmentally friendly and sustainable products can influence businesses to seek ways to satisfy customer demands	(Marino and Sabatini, 2014)
3.1.R12	Life Cycle Assessments	LCAs can provide in-depth insights to the process and can affect whether or not to lightweight, and how to amend processes to achieve a more sustainable design	(Herrmann et al., 2018) (BSI, 2006)

Table 3.1 – Influential Factors Affecting Lightweighting

3.4. Lightweighting Frameworks

The purpose of this section is to note down, visualise and assess different LW processes used in literature. Table 3.2 denotes a compilation of LW frameworks.

Section	Author	Lightweighting Process	Framework / Process Provided	Additional Notes
3.2.R1	(Tempelman, 2014)	7 Rules for Lightweight Design	- Design to requirements, nothing more - Choose factors that are recognized and relevant - Avoid bending and torsion - Consider topology and manufacturing when select materials - Use the minimum number of joints possible - Optimise until it cannot be any lighter - Consider using steel - Be inspired by nature	Requirements are identified and strictly designed to. Focused on LW design and optimisation. Holistic view of LW.
3.2.R2	(Czerwinski, 2021)	Multi-material selection algorithm for LW design	- Application - Customer requirements - Functional analysis - Material requirements o Possible material combinations o Constituent requirements o Constituent selection o Properties simulation* o Manufacturing principles*	Application and requirements are identified. Considers recycling. Detailed process for material selection.

			○ Specimen testing* ○ Feasibility studies* – if no, back to constituents' selection ○ If yes to the above 4 points, then optimisation ○ Manufacture prototype ○ Testing – if no, back to constituents' selection - Monolithic material selection research, if no, redo previous step - Monolithic material selection *All interlinked with one another	
3.2.R3	(Herrmann et al., 2018)	Levers of lightweighting	- Substitute materials for LW materials and consider multi-materials with joining techniques - Optimize a design's form and topology to reduce loads and weight. Done alongside material selection - Design and material selection needs to lead to being able to Manufacture and process the product - Reiterate the above 3 steps to achieve secondary benefits of LW (cyclic gains) - Define constraints and boundary conditions of performances and systems - Consider the end of life in the design as some LW materials have a negative impact on the environment	Holistic view of LW Secondary LW gains Considers EOL
3.2.R4	(Kaspar and Vielhaber, 2016)	Triangle of the LW design framework	- Requirements - Design ○ Load-specific and multi-functional approach - Manufacturing ○ New LW technologies - Materials ○ New engineering materials - All 3 pillars have cross component measures and form LW strategies, including qualities and costs - Product output	Holistic view of LW Quality and Cost considerations
3.2.R5		LW and material-oriented design (LMOD) methodology	- Task Clarification ○ Production planning ○ Specification - Conceptual design ○ System level ○ Subsystem level ○ Component level - Embodiment design ○ Assurance of properties ○ Joint sections - Detail design ○ Component level ○ Subsystem level ○ System level - Materials - Production ○ SOPs and system release - Use - End of life	Highly detailed cross over specifics EOL considered Joints shown in process Application and requirements are identified

<table>
<tr>
<td>3.2.R6</td>
<td>(Krause, 2012) referenced in (Kaspar and Vielhaber, 2016)</td>
<td>LW development methodology</td>
<td colspan="2">- LW project
- Task clarification
- Conceptual design
o Input of LW knowledge*
- Embodiment design
o Input of LW knowledge*
- Detail design
o Input of LW knowledge*
- Prototype manufacturing (through the use of computation tools mentioned below)
o Clarification of space and load case
o Topology optimisation
o CAD design
o Finite Element Methods calculation
▪ Feedback loop to above step
o Feedback loop to above step
- Testing
- Release
*Lightweight knowledge of construction techniques, engineering materials, composite materials, sandwich structures, laminate theory, manufacturing techniques, test methods</td>
<td>Good overview of LW input in manufacturing process
The implementation of 3 LW pillars.
Holistic view of LW
Original paper was in German, however, article that referenced it was in English.
Author deemed it relevant to include.</td>
</tr>
<tr>
<td>3.2.R7</td>
<td>(Ellenrieder et al., 2013) referenced in (Kaspar and Vielhaber, 2016)</td>
<td>LW development methodology</td>
<td>- Product/task
- System
- Product
- Conceptual design
- Conditional design
- Manufacturing and form design
- Weight check</td>
<td>- Product/Task
- Product
- Difficulties and potentials
- Amount and type of function
- Choice of an appropriate construction technique
- Material design
- Form design
- Manufacturing design</td>
<td>Function, price and weight are metrics used.
3 pillars considered
Holistic view of LW
Original paper was in German, however, article that referenced it was in English.
Author deemed it relevant to include</td>
</tr>
<tr>
<td colspan="3"></td>
<td colspan="2">Both processes above combine towards a theoretical product, which is then constructed. Afterwards, the function price and weight are assessed. If they meet requirements, target is achieved, if not, the findings are fed back to the initial product/task of each process above.</td>
<td></td>
</tr>
</table>

Table 3.2 – Lightweighting Frameworks, Table adapted from (Meina et al., 2018) and (Iddris, 2016)

The frameworks denoted several different methodologies and approaches to lightweighting. It is useful to collate and present them as similarities and differences that can be compared with one another. Three of the frameworks, Tempelman (2014), Czerwinski (2021) and Kaspar and Vielhaber (2016) are oriented towards design optimisation or materials selection processes, detailing further the necessary steps to achieving LW in that respect. Nonetheless, these frameworks still consider the

other two pillars of LW, namely, materials selection and manufacturing processes, pointing towards a holistic approach or consideration in LW. Interestingly, all frameworks are holistic in nature, referring to each of the pillars of LW at one point or another.

Most of the frameworks are oriented towards a product's design and manufacturing processes, generally starting from identifying the project and product requirements to design, ordering, manufacturing, testing and being in operation. This indicates the stages where LW is generally prevalent in a product's lifecycle. Herrmann et al. (2018) and Kaspar and Vielhaber (2016) both consider the products end of life, pointing towards sustainability being a driver in their research. Kaspar and Vielhaber (2016) and Ellenrieder et al. (2013) referenced in Kaspar and Vielhaber (2016) both have checks at the end of the processes to determine that the product is meeting requirements, either quality, costs or weight. Although all processes are holistic and even specialised in certain areas, it is interesting to note the order in which they apply each pillar after identifying requirements. The majority follow the same line, that is, design, materials and manufacturing, in line with a product's life cycle process, as would be expected.

A point noticed is the lack of emphasis in the majority of the frameworks is identifying the intentions to lightweight, as each driver will result in different outputs being assessed. For example, sustainability will result in an LCA being applied, with the impact the product has on the environment throughout its life being assessed alongside other weight metrics. Another example is a reduction of weight for functionality purposes, where performance parameters would be targeted at the start of the process and reviewed against at the end. It can be argued that the targets and outputs should be detailed and linked together in the LW framework applied.

3.5. Summary Points

In summary, LW is a popular implementation that is generally driven by the need to achieve better performance/functionality for a product, a more economical/sustainable product and for cost reductions leading to higher profits. Further key points identified in literature are

1- Unique attributes: LW consists of four main aspects, an intention to LW (not considered a pillar and not emphasized as much in literature, though emphasized from the interviews), design optimisation, materials selection and associated manufacturing processes. They all work together in a holistic manner to achieve a targeted output.
2- Types of lightweighting: there are various ways in which to LW, such as holistically, specifically, directly, indirectly and through an LCA, though, some are not commonly recognised.
3- Frameworks of how to lightweight and where it fits into a product design and manufacturing process.

It has also been recognised that lightweighting is an advanced skillset requiring unique training. It can be reasonably assumed that some businesses that want to lightweight but don't know how to might seek external support. No articles were identified by the author that sought the process of collaborating with an external partner seeking support in lightweighting. Further research into this subject area would expand the scope of general literature in lightweighting to incorporating collaborations.

This chapter has directly contributed to the second research objective by providing details on the LW management context, including the attributes, drivers, influential factors and frameworks. It provides a context that will develop the assessment tool through in the following chapter.

Chapter 4

Preliminary Scoping Interviews

4. Preliminary Scoping Interviews

Chapter Purpose	This chapter will discuss the preliminary scoping interviews conducted to identify a practical and appropriate issue in industry in the management of lightweighting and find out how businesses manage lightweighting.
Chapter Output	This section contributes to the second research objective by achieving the above points.

4.1. Interview Objectives

There were four interviews conducted on candidates with experience in LW or working within an industry where LW is a dominant application. The objectives of these interviews are to narrow the research area of interest to relevant industry issues, identify potential research topics leading to research questions and find out how businesses are managing LW. This includes but is not limited to perceptions of LW, associated processes, challenges and other relevant discussions. The Semi-Structured Interview Question Sheet can be seen in Appendix 1, the Participant Information Sheet can be seen in Appendix 2 and the findings of these interviews are detailed in Appendix 3.

4.2. Interview Outcomes, Discussions and Conclusions

There was relevant information collected from the candidates, which is detailed in Appendix 3. Table 4.1 provides an overview of the candidates as well as a comparison of certain relevant data points. For this chapter, key themes were reviewed, namely, the management of LW, relevant industry issues and potential research topics.

Candidate	Participant Job Level	Role Involves	Length of time in this role	Focus Area of lightweighting	Any pressure to reduce weights of products?	Tools used to measure lightweighting	Challenges	Disadvantages	Unorthodox Ways in which to LW	Definition of LW	How is innovation manifested in this company?
Candidate A	Senior Level	Participation, creating innovative initiatives lightweighting	Not provided	Materials Design Optimisation	Yes	Min. Weight vs Min. Cost	Experience, Quality of Training A right attitude Decline in manufacturing industry	Cost to change Risk involved for managers "If it ain't broke, don't fix it" mentality	Eating into reserve factors	N/A	N/A
Candidate B	Managerial	Driving and monitoring LW and/or other innovative initiatives participation, creating innovative initiatives Lightweighting Collaborating with others Networking	1-5 years	Materials Design Optimisation	Yes	Min. Weight vs Min. Cost	Expertise for lightweighting and composites difficult to train up people. Too many uninformed clients on justification of lightweighting	Cost implications struggling to find resource and experts in composites Risk in new processes implemented affecting the business, training staff, moving from the known methods to the unknown. LW tends to be aimed at composites	Recycling, considering end of life	"Taking a genuine concept that has clear benefits through the concept again of being lighter in weight. "	From the client - take their idea and develop it to achieving what they need and more. Bringing it to realization.
Candidate C	Senior Managerial	Driving and monitoring LW and/or other innovative initiatives participation, creating innovative initiatives Lightweighting Collaborating with others	10+ years	Materials Design Optimisation weight neutrality	Yes	Weight vs Cost	Integrating the necessary parts to achieve a change needed. (mapped out on a spider diagram)	Cost - Pushing boundaries on materials and processes new methods require qualifications, processes, any change is difficult and has a ripple effect.	Feedback loop to improve process time, requiring redesign, weight neutrality	Making things lighter.	Dedicated R&D department
Candidate D	Engineer	monitoring LW and/or other innovative initiatives participation, creating innovative initiatives Lightweighting Collaborating with others	1-5 years	N/A	Yes (Internally)	cost/kg	Integrating a change in a highly structured network.	Cost and necessity justification	Global lightweighting system. No	Making things lighter.	Well-structured company. LOPs and SOPs for everything

Table 4.1 – Comparisons Table between Candidates

4.2.1 The Management of Lightweighting

Several methods were identified in how the candidates and their respective businesses managed lightweighting. Some candidates, working in either research centres or industries that lightweight, distinguished the design process to be either of new designs/projects or working with established designs/projects. For new designs within the aerospace industry, lightweighting is given priority where cost is directly associated with the reduction in weight. For example, 1kg removed equates to $10,000 in savings for the end client.

4.2.1.1. The peripheral focus of lightweighting

Once designed, the reduction of weight moved into the periphery of focus and weight neutrality in the design was targeted for changes. This is mainly to prevent any further scopes of global design changes where local amendments are required. This avoids a knock-on effect of changes and a larger scope of design approvals. In the discussion with candidates C and D, the concept of weight neutrality was not associated with lightweighting to them. Though, upon review of the essential characteristics of lightweighting, weight neutrality can be considered to contain the necessary elements for it to be considered lightweighting in an indirect manner. The indirect nature exists since the aim is not to reduce the weight as much as possible, but to achieve a target weight by implementing lightweighting. More can be read on this in Chapter 5.

4.2.1.2. Radical vs. Incremental changes

During the discussions of new designs and established designs, the concepts of radical and incremental design changes were naturally linked. As the names suggest, radical implementations tend to have a significant shift not only within the redesign of the local component, but one that affects the global system, likely requiring alterations to already established processes, procedures, adjacent components, further approvals and training. Candidates noted that radical changes tend to put off senior management as significant financial and time investments are likely, with one candidate stating managers are likely to have the attitude “if it ain’t broke, don’t fix it”. However, during new designs and projects, radical changes are more welcome as the global scope is subject to approval, allowing the opportunity to make changes where necessary. Candidate C pointed out that a feedback loop was

usually considered, where changes that were wanting to be made from a previous project or earlier revision were collated and applied at this stage.

Related to the amendments within already established designs, incremental design change projects have a raised awareness of the knock-on effect that each change does. This defines boundaries where change can or cannot occur after a product has been approved and is in operation. Established businesses with developed processes and tried and tested designs are at a stage where they are building upon previous iterations of lightweighting that incremental advances are generally achieved, unless radical input is used. However, regulations and established methods discourage these radical changes. These restrictions lead to the emphasis upon a justification process prior to lightweighting to understand the advantages and disadvantages of a new implementation.

4.2.1.3. The need to justify lightweighting

All candidates have identified the need to justify lightweighting for any application or have a business case for it, applying at a minimum a cost to weight reduction ratio. However, no formal processes have been identified when asked if they had lightweighting processes. Candidate A stated that lightweighting was a scope, similar to standard design for manufacture. Candidate A noted that it was simply a case of using lightweight materials coupled with design optimisation. While this may be true, it can be perceived to be an incomplete view of lightweighting, where a key identifying factor for lightweighting is the need to employ a decision-making process on whether or not to lightweight, as noted by candidate B.

Furthermore, candidate B, identified that many businesses approaching research centres had a misunderstanding of the concept of lightweighting, thinking a lighter product equates to a better product and that it involves the use of composites. The candidate, noted that such businesses were not applying a significant enough justification process prior to approaching them, wasting the time of the research centre. The decision process to lightweight or not seems to become the starting point of lightweighting.

4.2.1.4. Design Integrity

Another point raised was achieving design integrity. That is, trying to achieve a lighter product pushes the design to maximum capacity. This boundary could be a stumbling block to designers and could potentially prevent the realisation of projects or designs, more notably, those with fewer resources or inadequate training. Some candidates discussed integrating components to reduce parts and joints to work around this. Candidates A and C identified challenging these boundaries and see if they are subject to change. This could be due to outdated standards or proving through further analysis that safety factors could be carefully reduced, while still maintaining design integrity.

4.2.2 Relevant industry issues and potential research topics

Multiple contributing factors discussed in the interviews point towards one underlying tone that is at the forefront in the field of lightweighting, namely, are businesses ready to lightweight or collaborate in lightweighting?

The underlying tone was made known by candidate B when discussing that many businesses were wanting to collaborate in lightweighting projects, but upon closer review, numerous businesses misunderstood the concept and its application. This misunderstanding seems to come from two points. Firstly, that lightweighting is using composites, which are perceived as stronger and lighter materials. While composites are common in lightweighting projects, using new materials is one facet of the lightweighting process, is not necessarily required and shouldn't be the go to option (Tempelman, 2014). Secondly, the "is it worth it?" factor, there must be a justification to implement the process. The influx of enquiries rejected by the business of candidate B seemingly indicates a lack of understanding and justification by businesses.

The justification can be through identifying financial impacts, timelines, scope, priorities required processes, environmental impacts, but seemingly most of all, having the required training to identify key parameters and metrics. Candidates A, B and C discuss the need for receiving high quality training, with two of the candidates stating this was an issue in the field.

Further contributing factors to lightweighting readiness identified are,

- Resources – making changes at a design level, such as the use of composites will require changes downstream, such as new tooling, training, and procedures.
- Established processes – Is there a current process in place or is this lightweighting project conceptual?
- Technology readiness – lightweighting utilizes technology and the availability of technology can influence the degree of readiness.
- Interdepartmental collaborations – lightweighting is holistic and requires a combined effort to materialize an innovative solution.
- Understanding the knock-on effects to changes. Some changes may require manufacturing changes, and long-term identification and justification, such as third-party approvals.
- Smaller businesses versus larger businesses. Larger businesses tend to have established processes, more resources and adequate training.
- Incremental or radical lightweighting – the scope of change
- The materializing of the lightweighting business case – there is a decision-making process involved in the desire to use it. What are the drivers for doing so?

Candidate B stressed that the collaboration readiness of businesses in lightweighting was a forefront issue in the research area. The research centre is having their performances effected by this need to sift out genuine collaborators. That, combined with the knowledge that there are several contributing factors providing depth to the issue, sets the scene for what this research will focus upon.

Other possible research topics were identified from the interviews. They were,

- Implementing cutting edge technological developments and the corresponding lightweighting processes that stem from them.
- Identifying the relationship between design integrity and lightweighting capacity.
- The multi-departmental efforts in global design lightweighting.
- The management of Carbon net zero in lightweighting.
- Cost analysis vs lifecycle analysis

    - research has been conducted in the life cycle analyses associated with lightweighting, and this. However, how much of this is being implemented in businesses, more specifically, those that implement lightweighting?
    - A key “worth it” factor is cost. However, how is this conducted and what is the scope of consideration of the product lifecycle?
- How to integrate a lightweighting process within an already established and complex system.
- The comparison of lightweighting and the decided use of composites in final designs.

Different techniques were discussed throughout all interviews, such as using different materials, advanced design optimisation, develop manufacturing processes, integrate components, remove joints, etc. The focus of this research is not to delve into these points; however, they will be discussed in Chapter 3 to provide information to the context.

4.2.3 Have the outcomes been met?

The interviews set out to achieve three main goals, they are stated below with the associated results.

1. Find potential research topics leading to research questions.

Potential research topics were identified in the interview and little to no information was found through a simple search on databases. The research objectives were framed based on the gaps in practice and knowledge identified.

2. Contextualize my research and narrow research area of interest.

Relevant information was gathered during these interviews with information gathered on some issues faced within industry, namely, design integrity and the need for training. Having this confirmed by candidates and developed further by candidate B to bring to scope a relevant key issue in innovation readiness sets the scene for this research with the context now being identified.

3. To find out how businesses are managing lightweighting. This includes but is not limited to perceptions of lightweighting, associated processes, challenges and other relevant discussions.

Relevant data was collected through these interviews. Different techniques were discussed, varying from applying standard manufacturing procedures to lightweighting, to indirect lightweighting through the application of weight neutrality. The points raised in these interviews will be used to guide the literature reviews on both innovation readiness and the context of lightweighting. From these scoping interviews a research problem was identified, that is, the innovation readiness of businesses wanting to collaborate with research centres in lightweighting. This will carry through into the following chapters with the overall objective to develop an assessment tool that might help support businesses and RCs collaborate more effectively in LW. This assessment tool or checklist would guide initial discussions that will hopefully lead to more fruitful conversations between them.

Chapter 5

Research Centres and Innovation Readiness Assessment Tools in Collaborations

5. Research Centres and Collaborations

Chapter Purpose	This chapter will elaborate on the systematic literature review process, the literature on businesses/RCs collaborating together and the innovation readiness tools/frameworks used by researchers in similar contexts. The theoretical concepts derived from this will be examined and considered for the development of a conceptual assessment tool.
Chapter Output	This section contributes to the third research objective, where a review of literature is conducted, the dynamics of RC/business collaborations are discussed and innovation readiness tools used in the assessments of collaborations are detailed and elaborated upon.

To start with, this chapter will look at detailed breakdown of the SLR, RCs, their roles, services, influential factors and intermediary nature. Secondly, the chapter will look at what literature says about businesses approaching RCs, including their cultures and environments. Thirdly, the chapter will look at collaboration dynamics between RCs and approaching businesses, including influential factors, collaboration needs, compatibilities, need and expectations. Finally, the chapter will evolve the literature review to reviewing elements and considerations of frameworks, detailing the various assessments of innovation readiness in collaborations.

5.1. Systematic Literature Review

A Systematic Literature Review (SLR) was conducted in a linear process to provide a high-quality academic review of literature on innovation readiness of businesses and research centres collaborating with one another (Easterby-Smith et al., 2008). The purposes and aims of conducting an SLR are to:

- Reduce bias through producing a review that is scientific in rigour, clear in its process, decisions and assumptions made so that it can be replicated (Dissemination, 2001) referenced in (Denyer and Tranfield, 2009)
- Provide as much relevant key literature in an achievable number of researches (Easterby-Smith et al., 2008)
- Identify where gaps in research are and to establish a valid and significant contribution that this research may deliver (Easterby-Smith et al., 2008) (Denyer and Tranfield, 2009)
- Create an output that can be utilized to advise policy, industry and future studies (Denyer and Tranfield, 2009)

The SLR was formulated by the systematic descriptions, reviews and processes used in Denyer and Tranfield (2009), Wetzstein et al. (2016), Easterby-Smith (2008), Tranfield et al. (2003) and University of Strathclyde (2019a). The following denotes the steps taken in this review.

5.1.1. Question Formulation

The question and scope were derived through a combination of the initial literature review and preliminary scoping interviews. The question of focus in the SLR is "What are the influential factors and tools used in assessing innovation readiness of businesses and RCs collaborating together?" The scope will later review and apply the context of lightweighting to these findings.

Denyer and Tranfield (2009) refer to the SLR as an independent study that investigates a defined research question. To establish the important aspects of a high-quality question, they refer to CIMO-logic used in (Denyer et al., 2008), where CIMO looks at the Context, Interventions, Mechanisms and Outcomes of a research question. tabulates the assessment of the research questions against CIMO logic.

While the question is non-specific to a field or industry, this research will be looking to apply the question to a context of LW or manufacturing (if LW yields no results), and correlate findings to results from the preliminary scoping interviews.

Component	Questions to Ask	RQ – What are the influential factors and tools used in assessing innovation readiness of businesses and RCs collaborating together?
Context (C)	Who are the individuals of interest?	RCs (Teams/individuals that interact with a client). Businesses wanting to work with RCs in LW (Point of contact and teams/individuals that interact with RC)
	Which interpersonal relationships are of interest?	Key individuals in various departments communicating to implement a specified goal (e.g. LW). It is reasonably assumed that RCs are knowledgeable in the field that they support businesses approaching them
	Which aspects of the institutional setting are of interest?	Cross departmental dynamics and communication to provide an outcome Businesses • Point of contact from business for expectations of RCs • Business cultures and environments Research Centres • Understand their expectations of approaching businesses • What are their roles, including as an intermediary?
	Which aspects of the wider infrastructural system are of interest?	Compatibility between RCs and approaching businesses. Identifying readiness through collaborations and LW readiness of the approaching business.
Interventions (I)	What is the intervention of interest?	Identifying parameters in innovation readiness relevant to RC/ approaching business collaborations, contextualize it through the integration of LW parameters. Create a assessment tool that would assist managing the influx of enquiries to RC as this was identified as a forefront issue in preliminary scoping interviews and literature.
Mechanisms (M)	What are the mechanisms of interest?	Filter between businesses that need LW and think they need to LW.
	What is it about interventions acting in a context that leads to the outcome?	The preliminary scoping interviews identified a need for defining innovation readiness in the LW context. This contextual application, which is identified as a gap in the knowledge, directly addresses this forefront issue.
	Why are mechanisms activated or not activated?	The scoping interviews and literature (Tann et al., 2002) indicate that too many businesses are approaching RCs looking to collaborate, but don't understand it's implication. They know it may be beneficial, when it perhaps it is not the case, potentially causing adverse effects to their own objectives. No available data on the subject matter and preliminary reviews identify a need to identify and address this.

Outcomes (O)	What are the relevant outcomes?	Identify innovation readiness assessment tools data on RCs and approaching businesses. Analyse findings to apply to the context of LW Provide the base knowledge to develop a assessment tool in assessing innovation readiness of businesses This aims to support businesses and RCs more effectively and efficiently, potentially save time and cost attending to irrelevant enquiries or ideas.
	What outcomes would be important to the individuals involved?	The individuals involved have identified a forefront issue to be a lack of innovation readiness and understanding by enquiring businesses. Getting information on the key parameters and contextualize them would help better understand this issue and possibly address it.
	How will the outcomes be measured?	Assess the developments in issues, identify trends and solutions made to use it. Influential factors of RCs Influential factors to Collaborations Assess the efficacy of techniques and methodologies used to address their said issues Identify contexts and their issues Frameworks used in literature in collaborations.
	What is the primary outcome and what are the secondary outcomes?	**Primary Outcome**: Identify influential factors and frameworks **Secondary Outcomes**: Identify associated techniques, methodologies and their relevant effectiveness. Collaboration dynamics Needs and expectations of collaborators Roles and responsibilities of RC and approaching businesses in collaborations
Validity of Research Question Construction		**The question is deemed valid as it aims to identify the innovation readiness assessment tool landscape, see what work has been conducted in this regarding RC/business collaborations. It primes the opportunity to contextualize the research for an assessment tool to support a relevant issue in industry.**

Table 5.1 – Question Construction using the CIMO logic applied from Denyer and Tranfield (2009)

5.1.2. Locating Studies

Denyer and Tranfield (2009) discuss that systematic reviews seek to identify, determine and evaluate as many studies relevant to the research questions. To find research pertaining to the research questions, research was reviewed through employing a systematic review of electronic databases, cross-referencing, examining textbooks and consulting with experts (Randolph, 2007, Denyer and Tranfield, 2009, Programme, 2018).

LW has been reviewed as a context of this study during the initial literature review to identify its attributes, techniques and issues. The SLR will focus on innovation readiness assessment tools of RCs and approaching businesses wanting to collaborate. However, any articles that are within the context of LW or are similar were reviewed with a higher priority over an article that applied innovation readiness to an irrelevant subject to this research.

5.1.3. Study Selection

Studies were selected and evaluated based on a timeframe, database selection, journal selection and article selection (Denyer and Tranfield, 2009, Wetzstein et al., 2016). The below sections discuss each of these selection criteria in further detail.

5.1.3.1. Time Frame

To find information written on the subject matter, for this, no time limits were applied to papers, therefore, all time periods will be considered. This will hope to provide a good development of the research conducted. Though, a priority is set on more recent papers for relevancy to current issues.

5.1.3.2. Database Selection

Through consultation with the Faculty Librarian, as well as reviewing other researchers, most notably Wetzstein et al. (2016), 5 aggregator databases in total were selected to provide the greatest coverage for management journals. They are Scopus, Web of Science, ABI Inform, Business Source Complete, and Gale.

Within Web of Science, the following databases were selected,

- Web of science Core collection
- Data citations index
- Kci-Korean journal database
- Russian science citation index
- Scielo citation index

5.1.3.3. Journal Selection

Since the topic is seen to be difficult to find information on this, peer reviewed work was considered and not limiting the journals by impact factor.

5.1.3.4. Article Selection

Following the process defined on the University of Strathclyde Research support site (2019b) which is illustrated in, keywords were piloted on the aggregator database Scopus and assessed based on relevancy, quality and quantity . If they were suitable, the literature review was conducted, if they were not suitable, new terms and keywords were attempted. This continued until suitable terms were derived. The trials that used LW terms yielded no relevant results with other keyword combinations. To address this, used keywords were independent of LW and during review, lightweighting articles and articles similar to this context were prioritised, e.g., advanced manufacturing, materials, design optimisation.

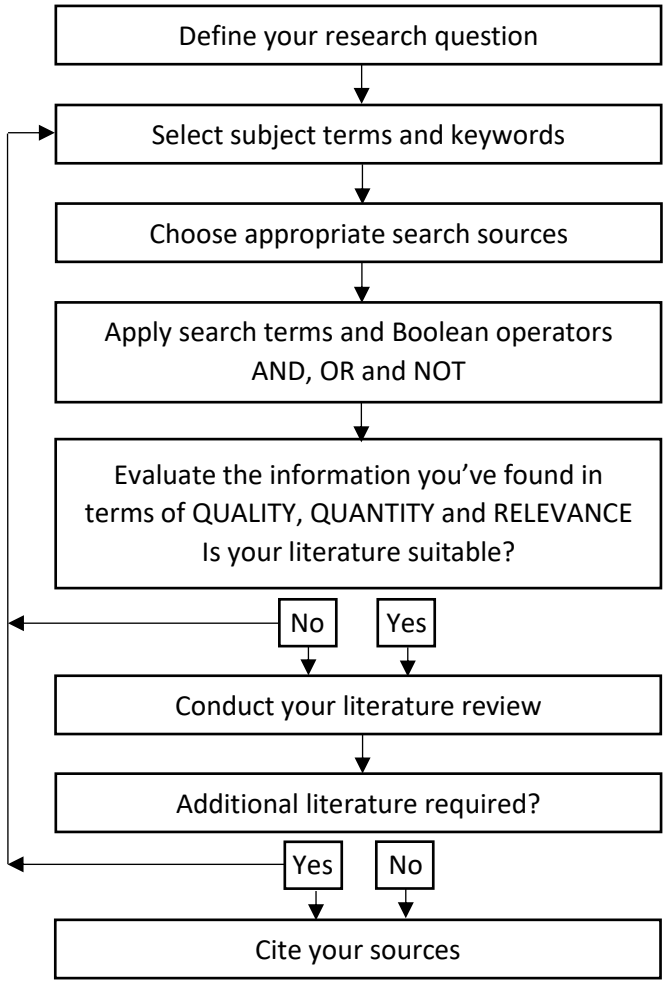

Figure 5.1. The literature research process used for piloting keywords (Strathclyde, 2019b)

Keywords

The keywords relevant to this research comprised of 4 different areas of interest. They are open innovation, research centres, maturity/capability frameworks and innovation readiness/capability. Each area of interest had keywords that were selected, they are detailed below.

1. **Open Innovation keywords (OI):**

Open innovation

2. **Research Centre keywords (RC):**

“research and technology organi*ation" **OR** "research center" **OR** "research centered" **OR** "research centers" **OR** "research centre" **OR** "research centred" **OR** "research centres" **OR** "innovation intermediar*" **OR** "research and innovation organi*ation" **OR** "Technology and innovation cent*" **OR** "Technology transfer organi*ation" **OR** "innovation center" **OR** "innovation centers" **OR** "innovation centre" **OR** "innovation centres" **OR** "intermediary organi*ation" **OR** "research institute" **OR** "university-industry" **OR** "research industry" **OR** "government labs" **OR** "public research organi*ation" **OR** "research and development" **OR** "R&D laboratories"

3. **Maturity/Capability Framework keywords (MCF):**

Keyword combination 1 **(MCF1)**: “Maturity framework” OR “capabilit* framework”

Keyword combination 2 **(MCF2)**: Maturity OR Capabilit* OR Collaborat* OR Framework.

If MCF2 yields too many results, only MCF1 is used.

4. **Innovation Readiness/Capability (IRC) keywords:**

Keyword combination 1 **(IRC1)**: “Innovation readiness”

Keyword combination 2 **(IRC2)**: “Innovation readiness” OR “innovation capabilit*” or “innovation capacit*”

Filtering keywords: collaborat*, matchmaking

In some searches, the resulting quantity of documents were significant that the search required a further filtering keyword. The keyword “collaborat*” was added to help identify a reasonable quantity of relevant documents. During article review, it was noted that relevant articles had used the keyword “Matchmaking”. Considering the relevancy of this term, it was added to the literature review to filter more relevant documents.

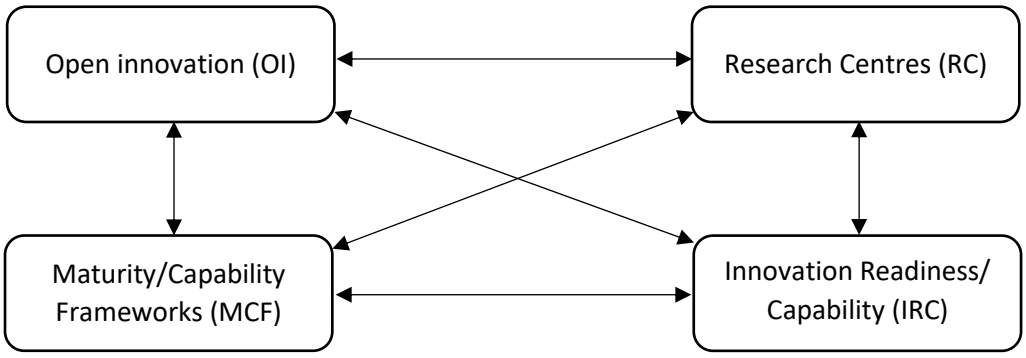

Figure 5.2. Areas of interest and combinations

illustrates each area of interest and the combination of areas that searched on the selected databases. They are detailed below. Following that is a table with the number of hits per search identifier.

For open innovation and research centres

Search Identifier A: OI AND RC

Search Identifier B: OI AND RC AND MCF2

For open innovation and maturity/capability frameworks

Search Identifier C: OI AND MCF2 AND collaborat* (In this case, MCF2 did not include the keyword collaborat*)

Search Identifier D: OI AND MCF1

For open innovation and innovation readiness/capability

Search Identifier E: OI AND IRC2 (There were very few terms, that only Innovation readiness was used)

For research centres and maturity/ capability frameworks

Search Identifier F: RC AND MCF1 (MCF2 yielded too many results when combined with RC and was excluded from the search)

For research centres and innovation readiness/capability

Search Identifier G: RC AND IRC2

For innovation readiness/capability and maturity/capability frameworks

Search Identifier H: IRC2 AND MCF2

Search Identifier I: IRC1

During piloting keywords, the keyword innovation readiness didn't yield many results. So, a search was conducted solely on IRC1.

Search Identifier J: OI AND "matchmaking"

		Aggregator	Aggregator	Aggregator (Academic)	Aggregator (Academic)	aggregator /Publisher	
		Proquest	EBSCO/ greenfile	Peer reviewed	Peer reviewed		
Identifiers	**Searching List To Do**	**ABI Inform**	**Business Source complete**	**Scopus (look at databases)**	**Web of Science (look at databases)**	**Gale**	**Total**
A	Open innovation AND RC	684 Too many results.	25	677 Too many results.	1759 Too many results.	Database not compatible with RC terms	25
B	Open innovation AND RC AND Maturity OR Capbilit* OR Collaborat* OR Framework	85	27	122	1	Database not compatible with RC terms	235
C	Open innovation AND Collaborat* AND maturity OR capabilit* OR framework	40	24	324 Too many results.	1125 Too many results.	8	72
D	Open Innovation AND Maturity/ Capability terms 1	3	0	5	2	0	10
E	Open innovation AND (Innovation readiness OR innovation capabilit* or innovation capacit*)	19	16	40	36	0	111
F	RC AND "Maturity framework" OR "Capabilit* framework	4	0	2	2	Database not compatible with RC terms	8
G	RC AND "Innovation readiness" OR "Innovation capacit*" OR "Innovation capabilit*"	8	24	20	42	Database not compatible with RC terms	94
H	innovation readiness OR innovation capabilit* or Innovation capacit* AND Maturity OR Capabilit* OR collaborat* OR Framework	2	1	4	7	0	14
I	Innovation readiness	9	8	9	11	1	38
J	Matchmaking and Open innovation	1	5	5	6	0	17
Total		171	130	207	107	9	624

Table 5.2 – Number of hits per search term

Filtering Criteria

The searches were conducted in exactly the same way through each database where possible to maintain consistency. During the review of articles, the subsequent filtering criteria was used to select articles.

- All industry sectors related to manufacturing are to be considered. Not doing education or animation etc.
- Collaborative efforts between two bodies, preferably between RCs and businesses that is relevant and translatable to the current field of interest.
- Peer reviewed articles only
- English articles only
- No magazines or newspapers

To help remove duplicates, Endnote was used to remove duplicates followed by a confidence check of removing them manually. At the end, a total of 57 articles were included.

5.1.3.5. New Publications after Literature Review

During the searching process, alerts were created for searches conducted to provide monthly email updates or RSS feeds of any new articles added. RSS feeds provide up to date information and content the moment they are added to a website. They were reviewed regularly and relevant articles were considered.

5.1.3.6. Flowchart of Systematic Literature Review Process

illustrates the systematic literature review process flowchart used in this research. This based on research from Wetzstein et al. (2016).

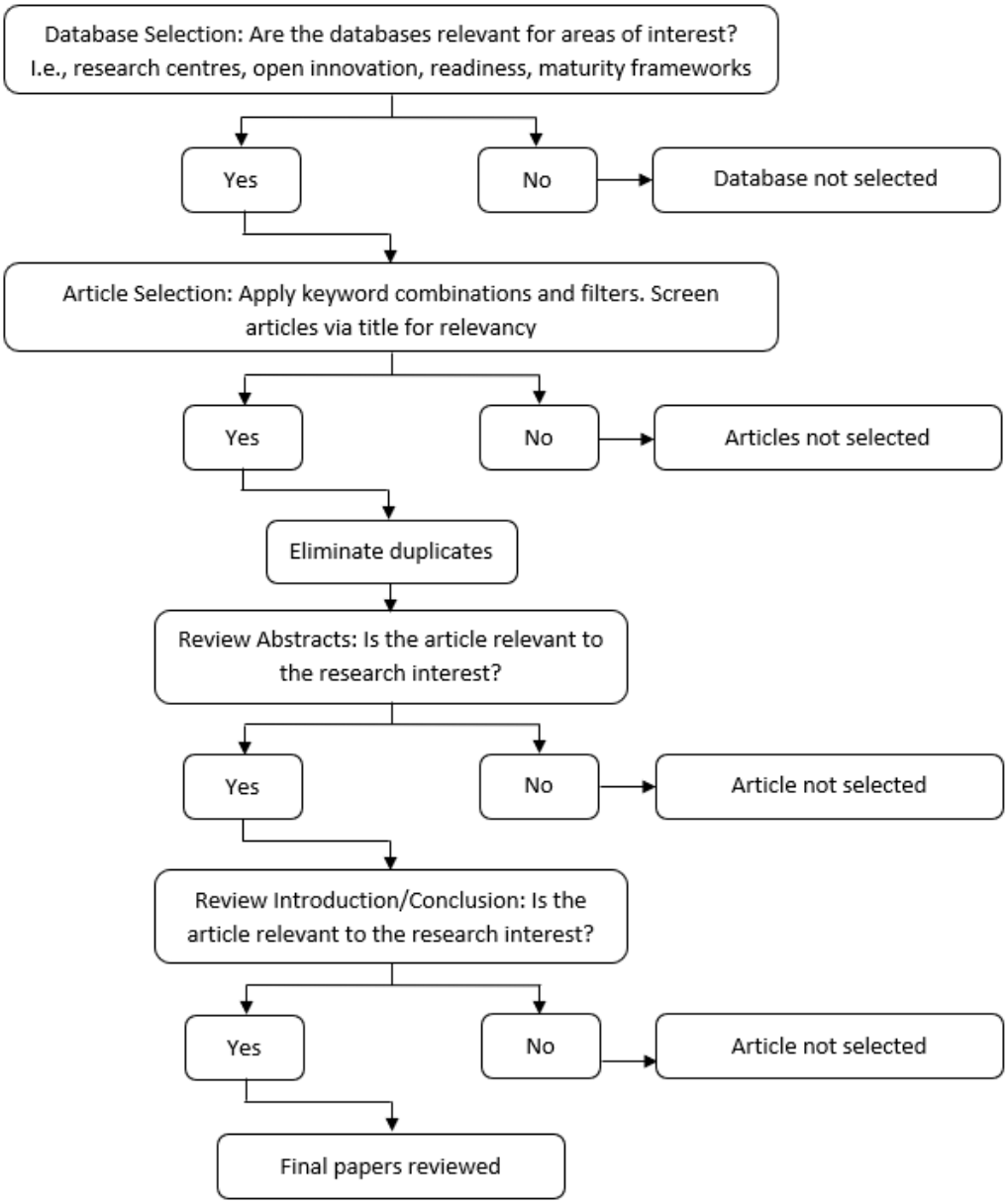

Figure 5.3. Flowchart of the applied systematic literature review process adapted from (Wetzstein et al., 2016).

5.1.4. Analysis and Synthesis

At the end of the systematic review, the goal is to have a comprehensive overview of the field of study and confirm the knowledge gap to which this research aims to significantly contribute to (Denyer and Tranfield, 2009).

Adapted from (Wallace and Wray, 2006, Solesbury, 2001), Denyer and Tranfield (2009) compile a list of questions to help extract information from the literature review. Questions considered in this review include the general details of the study, the type of study, research objectives, methodologies used, links to previous research, contexts, samples, findings and an overview to consider how convincing the research was.

5.2. Research Centres

Many different names of centres or organisations have been identified that are involved with industry in a research capacity. The following list of RC titles were collated. Namely, Research and Technology Organisations (RTO), Research Centres, Research and Innovation Organisations (RIO), Innovation Centres, Technology and Innovation Centres (TIC), Research Institutes, University-Industry Collaborations (UIC), Research Industry, Government Labs, Public Research Organisations, Living Labs and R&D Laboratories.

Such organisations tend to have similar goals in that they are bridging the gap between academia and industry through outputting high quality research, technological developments and innovation towards a positive impact on the economy (Hauser, 2010, Commons, 2011, Hepburn and Wolfe, 2014). They tend to collaborate with industry to develop research along the technology readiness level scale towards becoming ready for service and operation. (Smith, 2015, Gerdsri and Manotungvorapun, 2022, Hauser, 2010).

Each research centre will have its own purpose for its establishment and may differ from another, some focusing more on innovations, some focusing more on technological developments or some focusing on networking and intermediation. Their sources of funding may differ with varying degrees

of public and private funding (Hauser, 2010, Hepburn and Wolfe, 2014, Smith, 2015). The research intensity, technology intensity, end goals, degree and time of involvement can vary on a spectrum with each of them (Barge-Gil and Modrego, 2011, Hauser, 2010, Tann et al., 2002). For example, Research and Technology Organisations (RTOs) generally differ from University-Industry Collaborations (UIC) in focus, strategy, and services offered. RTOs will likely seek to develop firms to be more competitive in short-term projects, focusing predominantly on applied technical expertise and analysis support. UICs will be more geared towards generating knowledge through research, by supporting firms in long-term projects whilst providing training and access to equipment for the research to be conducted (Barge-Gil and Modrego, 2011, Giannopoulou et al., 2019).

There are also Innovation Intermediaries or Intermediary Organisations. They focus heavily on networking, providing a middle ground to connect and support businesses with similar research interests or goals to collaborate and innovate with one another. They also help provide financial support and find project related support if required (Barlatier et al., 2017, Abbate et al., 2019).

As there are many different types, the purpose of including these different RC titles was to find relevant articles in the subject area. The common thread sought after with the various terminologies is that the RC support and collaborate with businesses in projects of varying sizes to achieve a desired outcome. To clarify further, this research is looking for RCs that lightweight, and wants to identify the preliminary collaboration dynamics between these RCs and businesses. The scope of this research is businesses approaching an RC, looking to lightweight and the RC acting somewhat as an innovation intermediary to itself, and identifying the suitability of the business through assessing the business' innovation readiness to collaborate in this context.

5.2.1. Roles of an RC

According to the European Association of Research and Technology Organisations (EARTO) referenced in Barlatier et al.(2017) p. 97, RTOs' "*predominant activity is to provide R&D services, technology and innovation to businesses, governments and other customers*." They "*harness science and technology*

in the service of innovation, to improve quality of life and build economic competitiveness" (EARTO, 2015) referenced in (Martínez-Vela, 2016) p. 2.

They conduct applied R&D for firms in industry and are generally attributed to a certain field or focus, for example, biotechnical, advanced manufacturing, renewable energies, etc. (Tann et al., 2002). They typically support businesses in developing new products and processes or providing consultancy services. This can be but is not limited to, for the purpose of innovation, cost reduction, increasing energy efficiency, enhancing product quality, optimising user experience and reducing carbon footprint. Such research and innovation are carried out individually by organisations or through collaboration, where the participants often have complementary resources and capabilities. The make-up of these collaborators can be competitive enterprises, universities and RCs (Zhao and Wu, 2017). Tann et al. (2002) noted that RCs provide expertise in one or more areas of speciality, however, they rarely provide all the expertise necessary for the wider scope of large and broad projects. As such, more collaborators may be necessary.

Currently, academia would focus more of its research on long term conceptual progress, typically at lower Technology Readiness Levels (TRL), where its fundamental research output would impact industry and society over a significant period of time (more information can be found on TRLs in Chapter 5.6). Meanwhile, industry would focus on the immediate impact to production within a few months, that is, the higher end of TRLs. RCs complement this research and innovation ecosystem, as they have overlaps with both academia and industry. The majority of their focus is on mid-term and mid-level TRLs, where the innovation is applied within two to five years. As such, RCs bridge the gap between academia and industry (Hepburn and Wolfe, 2014, Katzy et al., 2013, Giannopoulou et al., 2019).

5.2.2. RC Services

RCs generally have a field of expertise and offer a wide range of services. Some of these innovation and R&D services can include, but are not limited to; Software know-how, hardware capabilities, design, manufacturing processes, knowledge transfer, training, networking, providing access to

technologies, private and public funding, speciality expertise services, prototyping capabilities, access to IP management, routes to volume manufacturing, knowledge and experience (Uribe-Echeberria et al., 2019, Yaghoubi et al., 2017, Hepburn and Wolfe, 2014, Hauser, 2010, Agogué et al., 2017, Giannopoulou et al., 2019). This is hardly an exhaustive list, yet, No RC will provide all of the services, but will typically specialise in a small subset of the above (Tann et al., 2002). There are exceptions of large well-established RCs, such as The Fraunhofer Society in Germany, that has a multitude of institutes. Below details some of the key roles, responsibilities and services of RCs that are within the context of this thesis.

5.2.2.1. Research, Development and Analysis

Research, development and analysis are widely renown for being a vital component of RCs. As experts in their field, RCs are often sought out by businesses to provide tailored studies. This helps businesses save research time and utilise the extensive specialised expertise of that RC to address their requirements. RCs that have available funding, are contacted by businesses with limited resources, particularly SMEs, who cannot afford detailed feasibility and acceptance studies, yet need the top-quality expertise they lack for feasibility and acceptance of critical technology or equipment they invest in. An identified cause of SMEs needing support is their clients delegating more responsibilities to them, and in turn requiring external support to keep the client due to a lack of expertise. Other studies include market analyses where RCs share key trends and findings that help their clients plan and strategize their business and technology roadmaps. Project or product analyses are other forms of tailored studies sought after. These look at lifecycle analyses and their relevant profitability calculations to determine the viability of seeing a project to completion. There are many other forms of custom studies and analyses such as authorisation studies and clinical test patterns; examination and evaluation of materials and innovative screening methods to name a few (Hepburn and Wolfe, 2014, Giannopoulou et al., 2019, Tann et al., 2002, Roper and Hewitt-Dundas, 2013, Eerola et al., 2015, Gerdsri and Manotungvorapun, 2022, Barlatier et al., 2017, Li and Zhu, 2021).

5.2.2.2. Third-Party Verification, Consultancy and Training

Articles read have pointed towards consultancy and third-party verification roles of RCs due to their expertise. Businesses invite key experts from RCs to sit on their Advisory Boards and help support the success of the businesses as they achieve their commercial and technological goals. This has been partly due to government funding and grant requirements for experts to serve on advisory boards, and in part due to competitiveness as well as the desire for cooperative innovation development. The support can also be in the form of assessing quality, refining the problem or pointing businesses in the right direction, or to the right references and published work to better understand and equip themselves to solve the problems they are encountering to be more competitive in the market (Tann et al., 2002, Albors et al., 2014, Uribe-Echeberria et al., 2019, Giannopoulou et al., 2019, Barlatier et al., 2017, Li and Zhu, 2021).

RCs usually have well established quality standards such as ISO certifications and serve as centres with recognised local or global standards. They are known to create standards, guides, procedures, inspections, certifications and accreditations in products, processes or services. Because of this, they use their knowledge and expertise, their technology know-how and may even have their own tests to conduct or in-house testing facilities. To compliment this, a core service for RCs is training. This may be generic content offered to a wide range of users to access, or tailored support for individuals, groups, or organisations. Training aims to develop the knowledge and experience individuals, and in turn, the workforce. It can help individuals who are changing fields of expertise and may have years of experience on one area and need new skills to adapt to a new area of application. An example of RCs that offer such training to upskill and reskill workforces is UK Research and Innovation in the United Kingdom (www.ukri.org), who are the UK's research and innovation centre. With over 3500 users each year, they support organisations and universities to produce highly skilled postgraduates and staff, thus equipping postgraduates with highly sought after and employable technology skills, and developing staff with numerical, problem solving, technological, and project management skills which serve the industry, commercial and government sectors (Tann et al., 2002, Albors et al., 2014, Giannopoulou et al., 2019, Howells, 2006, Hauser, 2010).

5.2.3. Influential factors for RCs

While the case for the need of RCs has been made through understanding the role they play in the ecosystem and value supply chain, many RCs face common barriers to their development and growth. In fact, a common problem faced by many RCs is that they often go through a phase of being unproductive. This is typically due to a number of reasons where the end result is a mismatch between the RC's strategic research direction, and the commercial development needs (Manotungvorapun and Gerdsri, 2021, Barlatier et al., 2017).

This section identifies influential factors for RCs. These factors are important to consider because they are potential variables that may impact the outcomes of collaborations between RCs and businesses in lightweighting. These influential factors, when harnessed positively open up opportunities and if mismanaged can stifle progress. Table 5.3 below lists key influential factors.

Section	Influential factors	Possible impacts (generally, not exclusively)	Reference
5.3.R1	Other RCs	Other RCs having a similar research focus within a geographical proximity can increase competition and hinder the output of an RC, but it can also cause the RC to develop its strategy to be more competitive.	(Tann et al., 2002) (Albors et al., 2014)
5.3.R2	Political, social, bureaucratical Issues	The absence of supportive legislations, regulations, management or a suitable organisational structure can create boundaries to RCs. This can also be through bureaucracies and social dynamics.	(Ankrah and Omar, 2015) (Goduscheit and Knudsen, 2015) (Kaymaz and Eryiğit, 2011) (Albors et al., 2014) (Uribe-Echeberria et al., 2019) (Bruneel et al., 2010) (Gerdsri and Manotungvorapun, 2022)
5.3.R3	Poor knowledge, processes, performance or resources	The lack of resources, training, knowledge and the management of them can negatively affect RCs. Such as high staff turnovers or matching industry wages.	(Kaymaz and Eryiğit, 2011) (Gerdsri and Manotungvorapun, 2022) (Ramli and Senin, 2015) (Mirza et al., 2020) (Ankrah and Omar, 2015) (Muscio and Vallanti, 2014) (Goduscheit and Knudsen, 2015) (Yaghoubi et al., 2017) (Tann et al., 2002)
5.3.R4	Poor marketing, communications, or negative reviews	Insufficient funding allocated to marketing, poor marketing such as over selling or negative feedback can all affect the RC image.	(Muscio and Vallanti, 2014) (Mirza et al., 2020) (Gerdsri and Manotungvorapun, 2022) (Kaymaz and Eryiğit, 2011)

			(Albors et al., 2014) (Bruneel et al., 2010) (Yaghoubi et al., 2017)
5.3.R5	Misalignment between research and industry	The expectations and goals for each can differ. The inability to align them can hinder an RC. For example, IPs, rules, available technologies.	(Muscio and Vallanti, 2014) (Gerdsri and Manotungvorapun, 2022) (Mirza et al., 2020) (Uribe-Echeberria et al., 2019) (Ankrah and Omar, 2015) (Mirza et al., 2020) (Goduscheit and Knudsen, 2015) (Bruneel et al., 2010)
5.3.R6	Financial Support	The saying “cash is king” is somewhat applicable here. The availability of sufficient funding can hinder operations or cause RCs to develop strategies to work with tighter budgets.	(Tann et al., 2002) (Ramli and Senin, 2015) (Gerdsri and Manotungvorapun, 2022) (Muscio and Vallanti, 2014) (Goduscheit and Knudsen, 2015) (Uribe-Echeberria et al., 2019)
5.3.R7	Insufficient procedures for collaborations	Lack of structure for collaborations can create negative experiences, output and reviews.	(Muscio and Vallanti, 2014) (Gerdsri and Manotungvorapun, 2022)
5.3.R8	Timeline requirements	The inability to meet production deadlines can cause RCs to lose awards and projects.	(Ramli and Senin, 2015) (Gerdsri and Manotungvorapun, 2022) (Mirza et al., 2020) (Uribe-Echeberria et al., 2019) (Goduscheit and Knudsen, 2015)
5.3.R9	Matchmaking and finding suitable collaborators	A prevalent issue brought up both in literature and in scoping interviews, the ability to find suitable collaborators, perhaps through a multitude of enquiries, can prevent funding, relativeness and hinder growth.	(Tann et al., 2002) (Gerdsri and Manotungvorapun, 2022) (Muscio and Vallanti, 2014) (Kaymaz and Eryiğit, 2011) (Mirza et al., 2020) (Goduscheit and Knudsen, 2015) (Uribe-Echeberria et al., 2019)
5.3.R10	Low interest in Research fields	Little to no interest in the research offered by the RC can prevent businesses wanting to participate. This could be due to mismatch between research and industry.	(Goduscheit and Knudsen, 2015) (Kaymaz and Eryiğit, 2011) (Manotungvorapun and Gerdsri, 2021) (Krawczyk and Pallot, 2014) (Bruneel et al., 2010)

Table 5.3 – Influential Factors Affecting Research Centres

Briefly, an example influential factor is matchmaking. Matchmaking is the intermediary role RCs play in introducing two third-parties together, where one has a need and the other is a good match in the supply chain for that need. This could be technology, or production, or process related, or even IP or

HR or legal or otherwise related. It is a process which generally establishes a comprehensive overview of collaboration parameters and presents an analysis of suitability for one another. Some matchmaking processes assess partners based on certain prerequisite criteria, some based on high level skills focussed in a research interest and others based on targets to achieve visions of a business (Gerdsri and Manotungvorapun, 2022, Krawczyk and Pallot, 2014). However, matchmaking has increasingly come under much pressure as the managerial and coordination costs of it can be rather high, and it is difficult to associate the cost-benefit of it, that is, what financial benefit does the RC gain by making these introductions (Holzmann et al., 2015). While the demand for matchmaking is high, the nature of the process, the benefits and rewards are not well documented, with little empirical data to help clarify the impact it has on all involved and the wider ecosystem (Krawczyk and Pallot, 2014).

It is important to validate this impact, as it allows for the development of processes and procedures to enable more successful collaborations, and it in turn enables open innovation in an organisation's culture. Furthermore, it would aid senior management to establish and promote these systems to working with OI external partners in accordance with the RCs objectives and strategic roadmap. This in turn would alleviate some of the other barriers, such as access to and the management of funding, as efficient networking would raise the RC's funding eligibility and prospects and the RC's role would be seen as one that fosters a culture of collaboration, innovation, knowledge transfer and development (Uribe-Echeberria et al., 2019).

5.2.4. The innovation intermediary nature of an RC

An innovation intermediary works to identify and successfully pair together collaborators with complimentary research objectives through their networking. They are the middle ground between collaborators, negotiating, problem solving, planning, communicating, allocating resources and working with innovation management processes to align collaborators and materialize the value of

the collaboration (Katzy et al., 2013, Krawczyk and Pallot, 2014, Agogué et al., 2017, Munkongsujarit and Srivannaboon, 2011).

A caveat to this apparently harmonious ecosystem is that longitudinally, the collaborators do not necessarily appreciate the input and participation of the intermediary. Rather, they value more the collaboration partner more. Perhaps this might be due to bureaucracy or high fees, potentially causing intermediaries to become outdated organisations. However, with the interconnected world, I collaborations are increasing in popularity and the need for intermediation will still exist. However, it's manifestation could be through a different channel (Chesbrough and Brunswicker, 2014, Lichtenthaler, 2013).

Some organisations, both RCs and businesses, are somewhat hybrid in nature with respect to the roles and responsibilities they are providing. They are taking on the role of an intermediary between themselves and potential collaborators, however are not exclusively an intermediary (Howells, 2006). This might be due to stakeholders pressing them to be more competitive in industry (Roper and Hewitt-Dundas, 2013). In context, self-intermediation by RCs allow for effective management of the influx of potential collaboration partners through the OI practices in identifying suitable collaboration partners (Uribe-Echeberria et al., 2019).

A factor highlighted during the preliminary scoping interviews indicated that an organisation's collaborative performance is hindered when they receive an overwhelming number of enquiries for potential collaborators. Resources are allocated to review and reply to each enquiry, following up on their requirements and presenting a possible match and solution for them, negatively affecting them financially through time and resource allocation (Tann et al., 2002). This can be seen to be applicable to any intermediary functioning organisation. Uribe-Echeberria et al. (2019) compliments this in that not many RCs have identified the kind of collaborators they are searching for and the collaboration scopes, namely timelines and costs.

Interestingly, Fisher and Qualls (2018) points out that the RCs are put in a position of collaboration dynamic power when they are approached by collaborators and need to self-intermediate. The authors noted they needed to identify how ready the businesses are to more effectively support them. Their methodology is reinforced by Lin and Wei's (2018) findings, in that identifying the

collaborator's innovation abilities is the most suited selection strategy for knowledge transfer. Kale and Singh (2007) proved that tool or a framework for intermediaries positively impacted collaborations. With Lichtenthaler (2013) highlighting the collaboration nature of RCs and intermediaries as high-yielding research topics, this leads towards developing an innovation readiness assessment tool for RCs identifying potential collaborators within the context of lightweighting.

To recap, the above section has described one of the major strands of the research objectives. By understanding the roles, influential factors, services and intermediary nature of an RC, it defines the expectations of one collaboration partner, arguably the leading partner. It sets a precedence for the fourth research objective's assessment tool development as the RC plays a self-intermediatory role. The following section will compliment this by looking at the other collaboration partner, how they fit into this, and what literature say about these businesses.

5.3. Businesses Collaborating with RCs

Lightweighting is a niche field of interest for which businesses seek assistance. To identify articles researching the collaboration of businesses and RCs, there is little to no literature available on context of lightweighting. This section briefly looks at what literature says about businesses collaborating with RCs, then identify and applying what is transferrable to the context, namely, the opportunities and challenges of businesses collaborating with RCs and business cultures and environments.

5.3.1. Opportunities and Challenges of Businesses Collaborating with RCs

There has been an trend in research for collaboration due to the lucrative possibilities of businesses working with external partners and the availability of technology to connect them with one another (Le et al., 2019). Such collaborations can result in cost savings, reduced risks, improved efficiencies, output and innovation quality amongst other values (Li and Zhu, 2021, Roper and Hewitt-Dundas, 2013). For many businesses, open innovation and/or collaborating with RCs is atypical (Swink, 2006). But generally, there is an identified value and potential that drives the effort to collaborate with an external partner (Van Looy et al., 2003, Roper and Hewitt-Dundas, 2013). To the business considering

collaboration with an RC, a popular underlying question that most articles have addressed is “What do businesses seek to gain from collaborating with an RC?” These possible gains, as well as barriers and enablers, were particularly common in literature.

Businesses collaborate for various reasons. Some common and important reasons are to get help in dealing with a difficult project or challenge that employees are struggling with (Kim et al., 2015), to get first hand access to tools and technologies and commercialize cutting edge research/knowledge to gain an advantage in the market (McConnell and Cross, 2019, Gerdsri and Manotungvorapun, 2022, Roper and Hewitt-Dundas, 2013), to access equipment or training (Giannopoulou et al., 2019) or to develop their knowledge, understanding, processes and procedures (José Silva et al., 2008). The advantageous reasons scope through every stage of a product’s lifecycle and any gain that a business could possibly get, such as financial or knowledge gain, network broadening, reducing innovative risk, increasing capabilities, innovative output and development, use of graduates, and the beneficial list goes on (Giannopoulou et al., 2019).

For any reason to collaborate, the business must be able to identify a shortcoming and validate its action to pursue the collaboration (Swink, 2006, BSI, 2019), as not every collaboration endeavour will succeed. The business needs to have clearly defined objectives with an understanding of the connections and communications required between each department (Fisher and Qualls, 2018, Swink, 2006). This is true for the context of lightweighting (Behnam and Cagliano, 2019). The preliminary scoping also identified that businesses were wanting to collaborate on lightweighting, but had not validated the need to lightweight in the products and processes, potentially impacting their products negatively. Other issues raised were the possible negative impacts of partnerships. Businesses may expect that these collaborations would solve their issues, but Chesbrough and Brunswicker (2014) revealed that businesses still faced the same problems after they had collaborated. Furthermore, each collaborator has their own interests and agendas, which could create conflicts (Gerdsri and Manotungvorapun, 2022). This further emphasizes the need to clearly define goals and establish a working agreement.

The size and type of businesses collaborating with RCs were noted in literature. Notably, larger established businesses with available resources and strategic goals were more likely to collaborate

with RCs, as opposed to Smaller and Medium Enterprises (SMEs) with fewer resources being more likely to collaborate with expert individuals (Shekar, 2014, Bodas Freitas et al., 2013, Gerdsri and Manotungvorapun, 2022). As for the type of businesses, those involved in the high tech or advanced manufacturing industries were the majority of businesses that collaborated with RCs, particularly those that were previously conducting product innovation (Chesbrough and Brunswicker, 2014, Fernández López et al., 2015).

5.3.2. Business Cultures and Environments

A business' culture or environment can significantly impact the entire collaboration process, even preventing it happening in the first place. Miscommunication and other boundaries between departments can occur, for example, between Engineering and Marketing or the RC interface team, where Marketing or the RC interface team exaggerate the capabilities or stages that Engineering are at in a product design (Shum, 2015). Or perhaps the business culture has a long history of a closed innovation system, making them apprehensive and thus, difficult for them to disclose information or processes with potential partners (Lee and Shin, 2017, Fisher and Qualls, 2018). Another issue can be unsupportive or inexperienced senior management in collaborations, with an unwillingness to invest and develop their employee's OI abilities, likely leading to failure in these attempts (Swink, 2006, Gribbin et al., 2018, Shum, 2015).

These points lead to a business needing to assess itself regarding its own ability and detail risks with collaborating and sharing sensitive information to potential RCs and even internally if needed (Van Looy et al., 2003). Lee and Shin (2017) reviewed internal business boundaries and acknowledged that businesses that struggled to collaborate with external partners, the staff in different teams struggled to collaborate with one another. This pointed towards the need of trusting other teams and equally important, including these teams in the collaboration process and the need for authoritative people, such as senior management to support businesswide collaborations (Swink, 2006, Lee and Shin, 2017, Gribbin et al., 2018).

5.4. Collaboration Dynamics between RCs and Businesses

Now that RCs and businesses have been reviewed individually, this section will discuss the findings of key collaboration parameters to measure and assess the dynamics between RCs and businesses. This research's primary focus is to assess the preliminary stages of collaboration, that is, the potential collaborators have just been identified and they are assessing each other for compatibility, such as partnership dynamics and the scope of the project.

5.4.1. Influential Factors to Collaborations

This section identifies influential factors to collaborations. These factors are important to consider because they are potential variables that may impact the outcomes of collaborations between RCs and businesses in lightweighting. These influential factors, when harnessed positively open up opportunities and if mismanaged can stifle progress. Table 5.4 below lists key influential factors.

Section	Influential factors	Possible impacts (generally, not exclusively)	Reference
5.4.R1	Relevant Subject Knowledge and employee capabilities	The more knowledge on a subject with employee skills and experience, the likelihood for a more meaningful collaboration	(Gerdsri and Manotungvorapun, 2022) (Van Looy et al., 2003) (Lin et al., 2020) (Eerola et al., 2015) (Armenakis et al., 1993)
5.4.R2	Previous Links with Collaborator	Previous links increase the likelihood of collaboration	(Gerdsri and Manotungvorapun, 2022)
5.4.R3	Geographical Proximity	Collaborators are more likely to work together if they are geographically close with one another	(Costa et al., 2020) (Gerdsri and Manotungvorapun, 2022)
5.4.R4	Senior Management and Leadership	Management having experience in collaborations or having an entrepreneurial mindset improved the likelihood of improved collaborations. Furthermore, without senior management support, the collaboration is likely to fail	(Van Looy et al., 2003) (Iddris, 2016) (Janevski et al., 2015) (Bertello et al., 2021) (Armenakis et al., 1993)
5.4.R5	Self-Assessment	Those that assessed the state of the employees and of the business were more likely to know what they needed in a collaboration and would focus collaborative efforts	(Gribbin et al., 2018) (Swink, 2006) (BSI, 2019) (Janevski et al., 2015)

5.4.R6	Identified Need to Collaborate	The collaboration partners must be able to identify the need to collaborate, defining mutual goals and objectives, or increasing the risk of a poor collaborative experience	(Manotungvorapun and Gerdsri, 2021) (Janssen et al., 2014) (Enkel et al., 2011) (Shum, 2015)
5.4.R7	Intellectual Property (IP) management	An agreement must for IP rights and management must be established to promote openness and establish trust	(BSI, 2019) (Janevski et al., 2015) (Meina et al., 2018)
5.4.R8	Absorptive or Desorptive capacity	The skill to take in new information and apply it in practice inwardly or outwardly can be a catalyst to collaborative success	(Moya et al., 2020) (Lichtenthaler, 2013) (Apa et al., 2020)
5.4.R9	Time constraints and Pressures	Individuals work differently under pressure; however, a tight or seemingly unrealistic deadline can affect the quality and output of collaboration efforts	(McConnell and Cross, 2019) (Shekar, 2014) (Bertello et al., 2021) (Meina et al., 2018) (Armenakis et al., 1993)
5.4.R10	Commitment & Value	Commitment to and value of the project is key to successful completion of the project	(Bertello et al., 2021) (Zhang et al., 2020) (Shum, 2015) (Armenakis et al., 1993)
5.4.R11	Trust	If a business does not trust their collaborating partner, they are more likely to be closed off.	(Moya et al., 2020) (Abreu et al., 2018)
5.4.R12	Training	Relevant staff need to be trained to conduct their activities competently	(Shum, 2015) (José Silva et al., 2008) (Janevski et al., 2015) (Piller and Ihl, 2009) (Bertello et al., 2021)
5.4.R13	Marketing	Good and relevant marketing skills are important. If a business oversells their capabilities, the increased chances of a bad collaboration experience.	(Janssen et al., 2014) (Shum, 2015) (Al-Ashaab et al., 2011) (Yildirim et al., 2022)
5.4.R14	Communication Channels	All relevant teams, both internal and external need to have established channels of communication and contribute.	(Swink, 2006) (José Silva et al., 2008) (Eerola et al., 2015) (Armenakis et al., 1993)
5.2.R15	OI Collaboration Dynamics and management	The ability to develop and implement processes, procedures and metrics for a collaboration with open channels of communication and feedback can improve the efficiency of a collaboration	(Uribe-Echeberria et al., 2019) (Meina et al., 2018) (Krause and Schutte, 2015) (Gribbin et al., 2018) (Yildirim et al., 2022)
5.4.R16	Business culture and dynamics	A nurturing environment that promotes OI, manages risks and accepts change are more likely to be successful in OI	(Iddris, 2016) (Moya et al., 2020) (Meina et al., 2018)
5.4.R17	Operational and strategic management	Having an established detailed plan, with associated risks being monitored increased the possibility of successful collaborations	(Bertello et al., 2021) (Janevski et al., 2015) (Wu and Chen, 2010) (Yaghoubi et al., 2017) (Meina et al., 2018)
5.4.R18	Knowledge management	The ability for a business to increase knowledgebase and develop lessons learnt increases the possibility for future collaborations	(Yaghoubi et al., 2017) (Iddris, 2016) (Waiyawuththanapoom et al., 2013)

5.4.R19	Funding and/or Capital	Funding must be agreed upon allocated prior to a collaboration	(Fernández López et al., 2015) (Van Looy et al., 2003) (Swink, 2006) (José Silva et al., 2008) (Armenakis et al., 1993)
5.4.R20	Resources	The lack of access to resources such as tools or equipment can halt the project	(Bertello et al., 2021) (Meina et al., 2018)
5.4.R21	Selecting suitable partners	Having a process to identify suitable partners increases the potential to a more meaningful and successful collaboration	(Janevski et al., 2015) (BSI, 2019) (Lin et al., 2020)

Table 5.4 – Possible Factors Impacting Collaborations

5.4.2. Motives Impacting Businesses to Collaborate

Prior to a collaboration, each party needs to validate the need to enter into one. They don't need to have all the answers, but enough to justify the partnership with respect to the context and circumstances, such as increased competition, government targets, legislature and economic environment (Armenakis et al., 1993). For example, the world today is seeing a shift of governments pressing lower carbon footprints with aims to be carbon net zero as a long-term objective. On a side note, lightweighting is a great driver and step towards achieving this target that many businesses can implement. Piller and Ihl (2009) noted that there must be a prevailing issue that requires urgent attention and addressing. Without this, the interaction is likely to be negatively hindered and not possible. The pressing issue must be correctly recognized otherwise all parties are addressing a wrong issue and unintentionally squandering efforts and assets (Munkongsujarit and Srivannaboon, 2011).

There are several reasons and needs to collaborate that have been mentioned throughout this chapter. A popular reason is a business facing a problem and they need help. This can be realised as new product or technology development, generating knowledge capital, stronger market position, exploring and establishing new scopes, edge on competition, reducing costs and developing new processes (Al-Ashaab et al., 2011).

5.4.3. Compatibility Checks

There are several different takes on what compatibility criteria need to or should be fulfilled to match suitable collaboration partners. There is no one set of criteria that fits all. They will need to be adjusted to suit each individual scenario as they all differ. However, there were key points identified that are transferrable to most scopes. The scope of this research considers a business to have identified a potential RC partner, and the RC intermediating for itself to identify if they are indeed compatible for collaboration.

5.4.3.1. Be ready and find suitable partners

"Our problem is not to find sufficient innovation partners; we need to understand how to find the right one, because searching for suitable partners interferes with the actual innovation!"

Candidate response in research conducted by Katzy et. al. (2013) pg. 305

The business and RC are both recommended to be ready to collaborate in advance with a commercial output in consideration (Van Looy et al., 2003). They need to find collaborators with similar strengths, agendas, strategies and competences that will develop each other towards their individually defined goals so that they can gain each from the collaboration (Li and Zhu, 2021, Piller and Ihl, 2009, McConnell and Cross, 2019, Fisher and Qualls, 2018, Moya et al., 2020). While differences will be present between the partners, their individual goals must be disclosed to one another and aligned to some degree so that they all can clearly see how they can benefit from the collaboration (Li and Zhu, 2021).

In addition to this, Manotungvorapun and Gerdsri (2016) conducted an exploratory study through structured interviews to identify a practical and generic template between University/Industry Collaborations (UIC) for businesses identifying university collaboration partners. The findings were that businesses tend to look at similar research areas and apply a trust factor. That is, do they trust them based on previous experiences, rumour and personal compatibility?

Businesses should not just approach any RC if they are specialized in that area, as the degree of technology readiness may vary. For example, RTOs focus more on projects that are higher up in the Technology Readiness Levels (TRL) chart and have a higher probability of commercializing the output. Universities on the other hand, will be more focussed on the lower end of the TRLs and are likely to provide service innovations (Giannopoulou et al., 2019). Whatever the outcome or goal that the business is seeking to achieve, they should approach the more suitable RC.

On a sidenote, there is a tendency that partnerships scope the entire product lifecycle. RCs and businesses must be prepared for the possibility that the collaboration may extend to that degree, even if that is not the agreed initial scope (Perkmann and Walsh, 2007). Furthermore, the timescale and costs would need to be considered as to finding an availability of when both partners are able to conduct the project (Bertello et al., 2021).

5.4.3.2. Points of contact

To determine points of contact within a business, Holzmann et al. (2015) discusses that matchmaking should occur not only at a business level, but at an employee level, as it is the employees who interact with one another, and their goals should be aligned with the overall business goals. The authors go on further to say that the departments that are relevant to the collaboration should be involved. For example, technical or manufacturing departments. The authors noticed the departments that established contact with a collaborator were specialised in strategy and not technology, leaving room for possible miscommunication. On the other hand, (Chesbrough and Brunswicker, 2014) and (Morse, 1998) referenced in (Shum, 2015) identified that senior-level management are the suitable employees/employers for points of contact as they operating at a strategy level, and are able to speak for the business. This seems to point to a need for involvement from various levels, both of senior management and of collaborating departments.

5.4.3.3. Problems, Solutions and Competences

It is more common that businesses seek to collaborate with RCs that have more advanced technological capabilities (Manotungvorapun and Gerdsri, 2021). An approaching business is expected to have product, technical and leadership competences. That is, they have experience with and an understanding of outstanding issues, are able to identify possible solutions and senior management being able to lead the business towards accomplishing their targets (Piller and Ihl, 2009, Van Looy et al., 2003, Janssen et al., 2014). These competences should translate to being common knowledge between them and the RC. This would provide the opportunity for easier communication, teamwork and participation (Manotungvorapun and Gerdsri, 2021).

Between the RC and business, there should be a suitable variance in the level of product and technical competences for the business to successfully develop upon. That is, the RC must be able to contribute to the collaboration through their knowledge input and demonstrate the ability to create and transfer knowledge. If this competency divide is too large or too small, then the partnership risks an inability to effectively collaborate or share useful information respectively (Manotungvorapun and Gerdsri, 2021, Li and Zhu, 2021, Wang, 2012).

5.4.3.4. Establishing Channels for Cooperation and Communication

The roles and responsibilities of each individual involved in the collaboration needs to be clearly defined as businesses have different ways of managing innovation (Janssen et al., 2014). Lianu et al. (2020) states that the method of collaboration should be firmly structured. Meaning, every aspect such as objectives or dynamics are regulated and have procedures. Swink (2006) breaks from this idea saying that there should also be unstructured collaborations allowing room for innovation. Swink's inclusion of unstructured interactions for the purpose of promoting room to innovate is interesting to note. However, each business and RC are different, and perhaps being fully structured works for them. This decision should be discussed and agreed upon.

Van Looy et al. (2003) brings up an important consideration to improve efficiency that people can overlook. That is, there needs to be skilled and experienced representatives from each department involved with the ability to coherent and clearly discuss project related matters (Howells, 2006).

5.4.3.5. Intellectual Property (IP) Management

An important element in that is strongly encouraged to be considered for every collaboration is IP management and the existence of a IP management team (Piller and Ihl, 2009). The European Committee for Standardization state that "*IP management involves identifying, tracing along time, deciding on publishing and potentially safeguarding IP on an individual IP level."* (CEN, 2014) Pg. 6. This establishes boundaries and procedures for each partner in what they can share and do with the collaboration knowledge and guards IP disclosed and created (Howells, 2006).

IP management must be developed and consented to by both parties prior to collaborating (Tann et al., 2002). Generally speaking, RCs want to publicise the knowledge created from the collaboration, such as in publications of the students involved. While businesses will be more inclined towards anonymity and imposing restrictions on what knowledge is shared, if any (Shekar, 2014, Foresight, 2013). Although IP management is extremely important, it can become a deterrent to collaboration if it is not tailored for each project and or there is little room for accommodating the needs of each partner (Shekar, 2014).

5.5. Innovation Readiness Consideration for this Context

As defined by Gribbin et al. (2018), Innovation readiness is "*the concept of providing an evaluation of the extent to which companies can sustain their ability to innovate*" Pg 5. The assessment of innovation readiness involves assessing factors both internally and externally based upon the input and intentions of the business it's desired end state and the reason for wanting to be at the end state must be identified and justified throughout the business. (Gribbin et al.,2018, AFRC, 2021, Banjongprasert, 2017, Shum, 2015). Table 5.6 highlights some of the assessment tools developed and used by researchers.

Some of the main challenges faced by businesses with respect to innovation readiness noted in literature include:

1. Resource allocation: does the business have sufficient resources, including employees, time, funding, and technologies for a project? (Gribbin et al., 2018, AFRC, 2021, Meina et al. 2018)
2. Senior management support: The support of senior management can help establish and promote successful collaborations or not (Armenakis et al., 1993, Holt and Daspit, 2015Van Looy et al., 2003, Iddris, 2016,).
3. Current skillset: Do the employees have the necessary skills or require further training? (Iddris, 2016, Gribbin e al., 2018, Holt and Daspit, 2015)

The problem identified in practice from the preliminary scoping interviews is that many collaborations in LW did not work out as successfully as the RC would have wanted them to. The discussion had pointed to businesses not being ready to innovate in lightweighting and collaborate in it also. This led to searching for an innovation readiness assessment tool for the RC and business to collaborate in lightweighting. While the following sections review innovation readiness tools as well as OI maturity and capability frameworks, this is for identifying translatable parameters to the research and problem in practice. The tool development for this research is not an OI maturity or capability framework, but an assessment tool for the context.

5.6. Review of Tools used in Literature

Innovation and collaborations are very difficult to quantify as there are numerous contributing factors that are difficult to capture, and arguably, some will be unaccounted for. Assessing abilities, including collaboration readiness creates a point of reference and starting point to which, each partner can identify with. This aids the partnership to communicate, plan and collaborate more efficiently with one another (Eerola et al., 2015, Abbate et al., 2019, Gerdsri et al., 2021).

The following section will review different types of assessments and frameworks that were found in literature. This includes, measuring parameters, methodologies, methods and tools used in the assessment of collaborations (Chesbrough and Brunswicker, 2014). Afterwards in Section 5.6, these frameworks will be assessed, compared and linked to each other to identify relevant themes that are seen to be applicable to this research. Furthermore, the assessment tool in Chapter 6 will link to the relevant literature for traceability purposes.

5.6.1. Types of Tools Used

From what has been gathered so far, the contribution leads towards the implementation of a assessment tool to assess the collaboration. From what has been observed in literature, there are various names for collaboration assessments used. These terms were bracketed into three main headings, namely, Open Innovation Capability/Maturity, Matchmaking and Innovation Readiness. While they all are closely linked and address similar points, for example optimisations and efficiencies, some are more specific and focus at different stages of the collaboration process. This section acts as a hybrid between the literature review and the assessment tool development. It addresses the third research objective by reviewing what literature says on assessments and frameworks, while also paving the way for the upcoming assessment tool development in Chapter 6.

5.6.1.1. Open innovation Capability/Maturity

Open Innovation (OI) is a term coined by Henry Chesbrough. He defines it as the incoming and outgoing flow of knowledge to develop innovation internally and to use of innovation output in the market (Chesbrough and Brunswicker, 2014). Researchers have developed upon Chesbrough's work to assess a business' capability or maturity to openly innovate as it is seen to be a vital evaluation for collaboration development (Zhao and Wu, 2017, Enkel et al., 2011).

OI capability is the capacity and/or ability for a business to innovate and collaborate with external partners based on knowledge internal and external to the business (Iddris, 2016, Wu and Chen, 2010, Yaghoubi et al., 2017, Moya et al., 2020). Furthermore, it is ideal for it to be an ongoing review beyond the scope of a project and over a period of time as opposed to a one-time assessment as it gives the subject an opportunity to measure it's OI capability development (Gerdsri et al., 2021). Maturity slightly differs from capability and is defined as the "extent to which a specific process is explicitly defined, managed, measured, controlled, and effective" Paulk et al. (1993) referenced in (Enkel et al., 2011) pg. 1164. Enkel et al. (2011) adapted these maturity parameter to OI and develop business profiles through a developed framework.

There are numerous methods of OI that go beyond the scope of this research, for example crowdsourcing. For the purposes of this research, the author will refer to that which is relevant in OI capability and maturity with respect to the research context.

5.6.1.2. Technology Readiness Levels (TRL)

Discussing the readiness of businesses, it would be remiss if the author did not mention Technology Readiness Levels (TRL). Commonly used in RCs, industry and academia, TRLs is a method of identifying how ready a technology is, starting from initial principles observed/reported to a technology being validated through and for operation (Sadin et al., 1989). Developed by NASA for space flight operations in the early 1970s for assessing the risk of technologies, TRLs have been translated and applied across industries and expanded upon to what is now generally recognised as 9 different technology readiness

levels (Lee et al., 2011, Raffaini and Manfredi, 2022). The UK Ministry of Defence defines the TRL levels as below.

TRL Level	***Definition***
1	*Basic principles observed and reported*
2	*Technology concept and/or application formulated*
3	*Analytical and experimental critical function and/or characteristic proof-of-concept*
4	*Technology basic validation in a laboratory environment*
5	*Technology basic validation in a relevant environment*
6	*Technology model or prototype demonstration in a relevant environment*
7	*Technology prototype demonstration in an operational environment*
8	*Actual technology completed and qualified through test and demonstration*
9	*Actual technology qualified through successful mission operations*

Table 5.5 – Technology Readiness Levels (TRL). Taken from (DASA, 2021)

5.6.2. Frameworks

From the references obtained within the literature, many researchers present frameworks to assess collaborations within various contexts, such as UICs, or customer/supplier, SMEs (Gerdsri and Manotungvorapun, 2022, Uribe-Echeberria et al., 2019, Bevis and Cole, 2010). Others review literature, compile and develop a framework based on their findings (Krause and Schutte, 2015, Waiyawuththanapoom et al., 2013, Wu and Chen, 2010). Table 5.6 provides an excerpt and overview of relevant frameworks used in literature. The details of these frameworks were synthesized and compiled into key innovation readiness parameters, where each parameter is elaborated upon. This can be found in Table 5.7.

Section	Authors	Assessment Type	Methodology / Method / Tools / Sample/ Point of Contact (POC)	Objective / Result	Framework Overview
5.6.R1	(Gerdsri and Manotungvorapun, 2022)	UIC collaborations	Methodology: Case study Method: Workshops Tools: Assessment tool Sample: 1 UIC POC: Academic partners and UIC committee of company	Objective: Framework and roadmap for developing UICs Result: Framework tested in case study. Proposed to test it further in various contexts	- Management of a company defines problems, needs from and wants of a collaboration partner - UIC team in company create tool to assess collaboration partners - Management and UIC team assess collaboration partners - UIC team reviews results and develops action plan to collaborate with partner
5.6.R2	(Uribe-Echeberria et al., 2019)	RTO OI Assessment	Methodology: Secondary Quantitative Method: Self-administered survey Tools: PLS-SEM (partial-least-square, structural-equation-modelling) Sample: 51 Spanish RTOs from register	Objective: Framework to assess an RTO's performance by looking at collaboration breadth, depth and processes Result: More collaboration partners and OI methods used strongly improve RTO output Senior management should promote OI and implement IP	- Organisational openness - Collaboration management - Intellectual property management
5.6.R3	(Meina et al., 2018)	OI readiness self-assessment	Methodology: comparative case study research Method: survey, case study Tools: questionnaire, interviews Sample: 29	Objective: develop a self-assessment OI readiness tool based on mindset and behaviour Result: Positive feedback. Future research can include capabilities and validation triangulation	- Motivating Factors - Networking Capabilities - Internal Culture Assessment - Knowledge and Experience - OI Capability
5.6.R4	(Tammela and Salminen, 2016)	Collaborative innovation	Methodology: Theoretical Method: Literature review	Objective and Result: Develop an interoperability map for channelling innovation	- Align company objectives - Align procedures for collaboration - Establish channels for knowledge exchange - IP management - Establish communication channels
5.6.R5	(Wu and Chen, 2010)	Technology Innovation capability in OI	Methodology: Theoretical Method: Literature review	Objective: Identifying and evaluating technological innovation capability in OI Result: Previous research reviewed and combined to develop an indicator system	- Manufacturing capabilities - Technological capabilities - Marketing capabilities - Strategic management capabilities
5.6.R6	(Krause and Schutte, 2015)	OI Lifecycle framework for SMEs	Methodology: Theoretical Method: Literature review	Objective: Develop an OI lifecycle framework based on OI, project management and continuous improvement methodologies for SMEs Result: conceptual framework developed and tailored to context.	- OI Planning and preparations o Company Facilitation Conduct OI o OI processes Metrics and assessment of OI o OI metrics o OI lessons learnt

					Develop OI o OI Developments o OI Implementations - Apply a feedback loop
5.6.R7	(AFRC, 2021)	OI readiness of companies collaborating with and RTO	Mixed Methods Survey Questionnaire, Likert Scale with opportunity to comment further	To assess the readiness of companies wanting it openly innovate with an RTO No results provided. Being used by an RTO.	- Company overview - Company structure - Technological capabilities and resources - Products and services offered - Manufacturing processes - Current processes and procedures - Available funding - Employee involvement and training - Channels of communication
5.6.R8	(Yaghoubi et al., 2017)	Innovation Capabilities (IC) in RCs	Methodology: Theoretical Method: Systematic Literature Review (SLR)	Objective: conduct an SLR on innovation capabilities in RCs Result: framework of ICs developed and tailored to context of RCs	- Leadership and senior management - Company resources - Knowledge management - R&D - Company Culture - Innovation processes that define performance and strategy
5.6.R9	(Moya et al., 2020)	Supplier/ customer co-innovation	Methodology: Theoretical Method: Literature review	Objective: Identify best practices for supplier/customer collaborations Result: framework of best practices developed and tailored to context	- Operations - Company - Strategy - Employee ability - Environment
5.6R10	(Iddris, 2016)	Innovation Capabilities	Methodology: Theoretical and Conceptual Method: Literature review	Objective: Provide a summary for an SLR on innovation capability and develop an IC framework Result: the majority of articles attribute and apply IC to companies or supply chain.	- Knowledge management - Company Culture - Absorptive and learning capabilities - Leadership capabilities - Collaborative capabilities - Concept management - Innovation strategies
5.6.R11	(Waiyawuththanapoom et al., 2013)	Open Innovation Readiness Assessment Model (OIRAM)	Methodology: Theoretical Method: Literature review	Objective and Result: Develop a Conceptual OIRAM to assist senior management in the task	Internal management of - Knowledge - Strategy - Change External Management of - IP - Networking

					- Environment
5.6.R12	(Armenakis et al., 1993)	Creating readiness for change	Methodology: Theoretical Method: Literature review	Objective: explain change readiness and identify influential factors Result: company beliefs, attitudes and intentions were identified as readiness factors. Methods to implement change internally presented.	- Assessment of current company standing - Identify company social dynamics - Prepare Influential strategies o Active contribution o Persuasive communication o Manage externally received information - Senior management Relay issues to company but applying preparations
5.6.R13	(Zhang et al., 2020)	Green innovation readiness	Methodology: Survey observations Method: survey observations Tools: questionnaire Sample: 340 companies	Objective: develop a green innovation readiness model Result: All framework subheadings proved to develop headings which leads to green innovation	- Technology readiness o Capability o Edge of competition - Company readiness o Innovation capability o Environmental awareness - Environmental readiness o Policy o Available Market
5.6.R14	(Bevis and Cole, 2010)	SME Open innovation readiness tool	Methodology: Fundamental Research Method: Literature review	Objective: OI readiness tool for low innovation SMEs Result: theoretical tool developed	- Understanding parameters of OI - Prepare to collaborate - Start collaborating - Collaboration management - Collate lessons learnt and apply feedback loop
5.6.R15	(Stevens et al., 2009)	Barriers and enablers in innovation	Methodology: Field research Method: case study Tools: interviews Sample: 20 programs from 12 government agencies Analysis: observations POC: representatives	Objective: develop an innovation readiness model, identifying barriers and enablers in innovation Result: developed a Y-model of innovation readiness	- Interpersonal features - Company culture - Project boundaries
5.6.R16	(Manotungvorapun and Gerdsri, 2016)	UIC selection criteria	Methodology: Exploratory Research Method: Case studies Tools: structured interviews Sample: 2 companies POC: senior management	Objective: Identify factors from literature that senior management consider for UIC Result: Senior management applied 1 of 2 methods, either trust, network and previous experience with university collaborators, or they apply a systematic approach to aid decision-making.	- Skills and abilities - Ability to apply research output - Technical communication abilities - Access to resources - Mutual goals - Adaptability - IP management - Compatible working styles - Trust

5.6.R17	(Abbate et al., 2019)	Open Innovation Digital Platforms (OIDP)	Methodology: Qualitative case study Method: Case study Tools: semi-structured interview Sample: 1 POC: consultant/manager	Objective: Identify how OIDP contributes to OI processes and knowledge co-creation Result: Conceptual framework proven to aid ideation based on scope	- Define the problem - Find collaborators - Collaborate
5.6.R18	(Ye et al., 2012)	Collaboration dynamics by an innovation intermediary	Methodology: Positivist exploratory case study research Method: Case Study Tools: interviews Sample: 4 innovation intermediaries Analysis: qualitative POC: 2 approaching companies, 2 employees managing OI and 2 experienced intermediaries	Objective: identify performance and value contributions of innovation intermediaries Result: main parameters defined and hypotheses developed from these parameters	- Company defines the problem - Intermediary seeks match problem with a potential suitable partner - Intermediary sift through proposed ideas and matches partners
5.6.R19	(BSI, 2019)	Guidance on innovative partnership	British standard	Objective and result: Create a reference point to guide in participating in collaborations	- Choose to participate in a collaborative innovation - Collate, sift and choose a partner - Align with one another in objectives - Create an agreement of collaborating dynamics, including understandings and objectives
5.6.R20	(Manotungvorapun and Gerdsri, 2021)	Matching quality of UICs	Methodology: Literature review and Case Study Method: Case study Tools: interview Analysis: score card rubric, hierarchy decision modelling Sample: 1 company with UIC experience POC: R&D manager	Objective: develop a framework to test the matching quality of UICs Result: detailed matching quality criteria for assessing	- Set conditions to analyse UIC match quality - Create a framework to assess match quality - Create metrics - Apply weighting factors - Create benchmarks - Assess academic partners - Compare quality of matches of academic partners and against company

5.6.R21	(Janssen et al., 2014)	Innovation intermediary competence model	Methodology: Explorative
			Method: Case studies
			Tools: case study protocol
			Sample: 14 cases
			Analysis: coding
			POC: project managers and experts in the project
				Objective: identify intermediary responsibilities in technology-based innovations
				
				Result: Intermediaries are most effective in the initial stages of innovation.
					- Ideation
					  o Problem / Possible solution
					  o Technologies needed
					  o OI justification / partners / budget
					- Conversion
					  o Define boundaries and dynamics of collaboration
					  o Knowledge flow contribution, IP management
					  o Assign roles and responsibilities
					  o Dynamics developments and results
					- Diffusion

					○ Impact of work together to collaborators ○ Impact of project on market ○ Possible future collaborations
5.6.R22	(Enkel et al., 2011)	OI maturity framework	Methodology: Qualitative Exploratory research Method: case studies, workshops Tools: Questionnaire, interviews, workshops Sample: 10 companies for workshops 5 case studies High tech international companies POC: innovation managers	Objective: Create an OI maturity framework to measure OI excellence Result: company performance (perception vs. actual) affected answers Modularize framework to avoid exhaustive irrelevant data collection	- Innovation environment ○ Integrate OI into communicated strategy ○ Senior management support of OI ○ Defined OI goals ○ Create incentives to openly innovate ○ Give employees power to start OIs - Identify partner capabilities ○ Partner trust ○ OI intensity ○ Standardised processes and procedures ○ Ability to work with diverse partners ○ Network of diverse partners ○ decision process for partner selection ○ OI training for employee - Internal company processes ○ Dedicated team ○ Communication channels ○ Resources ○ Knowledge and IP management ○ Result access and monitoring
5.6.R23	(Shum, 2015)	Innovation readiness	Methodology: Survey and case studies Method: Survey, data-mining, case studies Tools: Postal Questionnaire, Interviews Sample: 81 manufacturing companies POC: Senior management	Objective: Create a tool to assess innovation readiness Result: Validated through triangulation	- Leadership and vision ○ Championship ○ Vision ○ Entrepreneurship - Renewal and innovation ○ Innovation and idea management ○ Product development ○ R&D ○ Training - Internal capability and process ○ Project management ○ Teamwork and diversity ○ Process capability - Customer and Market Centric
5.6.R24	(Al-Ashaab et al., 2011)	UIC impact	Methodology: Case Studies Method: survey, case studies Tools: interviews, questionnaire	Objective: Measuring the output and effect of UIC collaborations	- Internal processes - Company Capitals - Strategic Knowledge Partnerships

			Sample: 2 case studies, 10 surveys	Result: balanced scorecard successfully proved for measuring, monitoring and improving UICs	- Innovation - Sustainable development - Competitiveness
5.6.R25	(Yildirim et al., 2022)	Innovation decision-making model	Methodology: Theoretical Method: Fuzzy multi-criteria-decision-making, survey Tools: questionnaire Analysis: Delphi, Fuzzy ANP, Expert group III, likert scale Sample: 8 individuals POC: experts	Objective: Use OI structure to develop innovation decision making model Result: Link can be established based on certain connections between OI and innovation parameters	- Company features - Industry features - Innovation methodology - Knowledge management and capability - Company culture - Project scope - Marketing - Innovation methodology - IP management - Knowledge management - Network management
5.6.R26	(Evans and Johnson, 2013)	Early-stage business model innovation	Methodology: Theoretical Sample: Lockheed Martin	Objective: Create innovation readiness levels based off of TRLs Result: framework developed to identify capabilities and required resources to develop business models	- IRL1: General specification of capabilities - IRL2: Detailed specification of capabilities - IRL3: Active development of capabilities - IRL4: First general demonstration of capability achieved - IRL5: Good demonstration of capability achieved - IRL6: First demonstration of capability in market - IRL7: First sale of final product - IRL8: Company successfully using capability - IRL9: Capability frequently used throughout production
5.6 R27	(Emden et al., 2006)	Emergent theory of partner selection for creating product advantage through collaboration	Methodology: Case Studies Method: Case studies, interviews Tools: Narrative analysis from case studies technique Sample: 4 case studies with 8 companies	Objective: Develop a process for selecting collaborative partners in new product developments with the maximum potential to create value. Result: partner selection through 3 phases and 3 decisions to identify a choice of partner	- Phase 1: Technological Alignment - Decision 1: Develop a mutual understanding of technologies and their implications in the market - Phase 2: Strategic Alignment - Decision 2: Establish a team to develop the initial codevelopment project specifications. - Phase 3 Relational Alignment - Decision 3: Determine financial and legal feasibility of codevelopment project and create organisational acceptance.

Table 5.6 – Overview - Anatomy of Frameworks Used in Assessments of Collaborations relating to Innovation Readiness, Adapted from Meina et al. (2018)

5.7. Review of Assessment Types, Frameworks, Methodologies and Methods used

5.7.1. Assessment types

There were several points of interest identified in literature. Firstly, the applied contexts for which assessments were conducted. Most articles aimed to create a generic framework template of innovation and collaboration assessments for researchers and those relevant to use and build upon (Waiyawuththanapoom et al., 2013, Stevens et al., 2009, Armenakis et al., 1993, Iddris, 2016, Enkel et al., 2011). Some were context specific in their applications to a seeker/host assessing a potential partner, such as businesses assessing academic partners, customers assessing suppliers and innovation intermediaries assessing the compatibility of two partners (Gerdsri and Manotungvorapun, 2022, Manotungvorapun and Gerdsri, 2021, Moya et al., 2020, Ye et al., 2012, Janssen et al., 2014)(Emden et al., 2006). The assessments extended further to self-assessments in various contexts, such as SMEs, RCs and family firms (Krause and Schutte, 2015, Bevis and Cole, 2010, Uribe-Echeberria et al., 2019, Yaghoubi et al., 2017, Holt and Daspit, 2015). Some assessment's contexts were characteristic oriented, such as innovating more sustainably, working with digital platforms or assessing technological readiness (Abbate et al., 2019, Zhang et al., 2020, Wu and Chen, 2010).

For this research context of RCs, articles were limited in self-assessment. That is, the research centre conducted and assessment for itself. The closest tool was from the Advanced Forming Research Centre (AFRC). They developed an online practical innovation readiness self-assessment tool for seekers approaching an RC (AFRC, 2021). Although, this wasn't a peer reviewed research article and no article was found on the context, it did provide valuable insight and inspiration as to what parameters an RC was assessing seeking businesses on. Questions and parameters were inclined more towards industry rather than academia, where items such as scrap rates and reworks on the shop floor were reviewed.

One interesting article is from Emden et al. (2006), where a partner selection theory was proposed to find a partner with maximum potential of value creation with a new product development. This framework consists of 3 phases of partner alignment with a decision-making stage after each phase,

and based on these criteria aligning was a partner identified. The researchers pointed out that technological alignment alone was insufficient, rather, strategic and relational alignments were also required. The first phase considered a technological alignment, where there is a check of technological ability and compatibility. This first alignment would initiate a decision on whether or not they should collaborate. The second phase is the strategic alignments, with the purpose of identifying motivations, goals and of preventing conflicts for partners being current or potential future rivals. The final phase is relational alignments, with checks regarding maintaining the working relationships over a period of time. Manotungvorapun and Gerdsri (2015) take this work a step further and creates a grading scale for the framework to determine the match quality. This is done through a radar chart with acceptability criteria, rejection criteria and pending criteria, where further investigation is required to determine acceptability or not.

A thought-provoking article was from Yildirim et al. (2022), where the authors developed a decision making model that each stage varied depending on the information gathered in the previous stage. This raises the question "are there any interactive frameworks that tailor to the scenario to help prevent exhaustive and potentially unnecessary review points?" Some article do provide step by step guidance (Armenakis et al., 1993, BSI, 2019), however the interactive nature of assessment wasn't found for the applicable context unless non rigid data collection methods were applied, such as semi-structured interviews or surveys.

5.7.2. Framework Observations and Results

A review and compilation were undertaken of the detailed stages of frameworks used in literature and bracketed under common themes. The purpose of this is to aid in identifying key components of frameworks used in related literature and apply parameters relevant to this research context. This method can be seen to be applied some researchers such as Zhang et al. (2020), where they introduced environmental parameters to the framework in assessing a business' green innovation readiness. It was identified that most frameworks iterated the same parameters or parameters that fall under similar categories. For some, the parameters were altered, partially considered or filtered towards their context. Some frameworks seemed exhaustive. They were either an exhaustive

assessment or they were the outputs of literature reviews for assessing OI collaborations. The 14 relevant parameters or themes identified from this that are compiled in Table 5.7 are listed below. Table 5.7 further elaborates on each of these points.

1. Senior Management and Leadership
2. Operational and Strategic Management
3. Company Culture and Dynamics
4. Communication Channels
5. Employee Capabilities
6. Technological Capabilities
7. Available Resources
8. Marketing
9. Knowledge Management
10. Reasons for Collaborating
11. Partner Selection
12. IP Management
13. OI Collaboration Dynamics and Management
14. Feedback Loop for Development

Section	Innovation Readiness in Collaborations Parameters (Themes identified in literature)	Compiled Detailed Stage / Assessment Points mentioned within this Parameter	Reference
5.7.R1	Senior Management and Leadership	- Does senior management actively develop morale? - Are employees encouraged and supported? - What are the business' management capabilities? - Are senior management capabilities measured? - Does senior management promote a culture of involvement? - Are employees encouraged and supported? - Is senior management supportive and involved in OI? - Does senior management promote new ideas and discuss innovations?	(Yaghoubi et al., 2017) (Iddris, 2016) (Wu and Chen, 2010) (Uribe-Echeberria et al., 2019) (Meina et al., 2018) (AFRC, 2021) (Zhang et al., 2020) (Enkel et al., 2011) (Shum, 2015)
5.7.R2	Operational and Strategic Management	- What are the innovation decision-making capabilities? - Can resources be procured and applied successfully? - Are there processes and procedures for decision making and innovation? - Are there metrics for innovation? - Is innovation managed? - Are there processes and procedures for decision making? - Are business strategies compared against developments and communicated to employees? - Is there a process for managing conflicts? - Are innovations internally campaigned to raise awareness? - Are project lifecycle timelines defined? - Are there process charts? - Do the processes distinguish key points that add significant value to products? - Are business barriers identified? - Are the barriers for scrap and rework rates identified? - Is there a process to evaluate the losses due to scraps and reworks? - Have innovations being previously applied within all processes? - Is there a clear and concise strategy for technology? - What are the successful outcome percentages of R&D? - How much resource, such as employees, time, funding, technologies are allocated to R&D? - What are the experiment parameters? - Is there a track record for previous applied innovations introduced? - Is there a strategy to develop innovations?	(Yildirim et al., 2022) (Wu and Chen, 2010) (Yaghoubi et al., 2017) (Meina et al., 2018) (AFRC, 2021) (Moya et al., 2020) (Iddris, 2016) (Waiyawuththanapoom et al., 2013) (Zhang et al., 2020) (Bevis and Cole, 2010) (BSI, 2019) (Enkel et al., 2011) (Al-Ashaab et al., 2011)

5.7.R3	Company Culture and Dynamics	- Are employees open to OI? - Are external resources, namely, knowledge and technology valued? - Do employees actively use external resources? - Does the company have defined goals? - Does the company identify barriers? - Does the company measure performance? - Does the company promote teamwork? - How does the company provide support? - Is there allocated time to innovate? - Are risks managed and mistakes tolerated? - Are employees given the ability to make decisions? - Are influential factors addressed and improved upon, and applied to the company's advantage? - Does the company culture accept change? - Is there a suitable environment to promote R&D? - Does the company allow flexibility to manage irregular conditions?	(Meina et al., 2018) (Yaghoubi et al., 2017) (Iddris, 2016) (Krause and Schutte, 2015) (AFRC, 2021) (Waiyawuththanapoom et al., 2013) (Enkel et al., 2011) (Armenakis et al., 1993) (Zhang et al., 2020) (Bevis and Cole, 2010) (Stevens et al., 2009) (Abbate et al., 2019) (Shum, 2015) (Gribbin et al., 2018) (Al-Ashaab et al., 2011) (Yildirim et al., 2022)
5.7.R4	Communication Channels	- Are performances measured and relayed to employees? - Does the business structure allow for omni-directional communications? - Are relevant information and knowledge shared between departments, suppliers, and customers? - Are communication channels set up for external collaborations and publications? - Are there channels of communication between different levels in a business? - Does the business develop networks for OI involvement? - Does the business already have a network for technological resource access? - Can collaborators be added to the network easily? - Can employees access partner's resources? - Are there communication channels for sharing knowledge with collaborators?	(AFRC, 2021) (Iddris, 2016) (Moya et al., 2020) (Meina et al., 2018) (Waiyawuththanapoom et al., 2013) (Armenakis et al., 1993) (BSI, 2019) (Yildirim et al., 2022) (Enkel et al., 2011)
5.7.R5	Employee Capabilities	- Do employees have absorptive capacity? - Are employees skilled technically in relevant and respective areas? - Is there a skills matrix for employees? - Have previous and future skills been compared? - Are gaps being addressed? - Are all staff involved in innovations trained for innovations? - Are there mind-mapping sessions for all staff? - Are employees motivated for ideations? - Are learning abilities developed? - Is training available?	(Moya et al., 2020) (AFRC, 2021) (Iddris, 2016) (Wu and Chen, 2010) (Armenakis et al., 1993) (Manotungvorapun and Gerdsri, 2016) (BSI, 2019) (Enkel et al., 2011) (Shum, 2015) (Yildirim et al., 2022)
5.7.R6	Technological Capabilities	- What is the quality of technological output? - Is there a need for sourcing technologies externally? - What are the learning capabilities of seeking external technologies? - Are innovations backed by technology? - Does the business have technological resources abundantly?	(Wu and Chen, 2010) (AFRC, 2021) (Waiyawuththanapoom et al., 2013) (Zhang et al., 2020) (Stevens et al., 2009) (BSI, 2019) (Janssen et al., 2014)
5.7.R7	Marketing	- Has a market been identified for this technology? - What percentage of the market does the business have in this technology? - Is there a brand for this technology? - Has a supply chain been established? - Is the business able to access external knowledge from the market? - Is the business collating market information? - Does the business have the ability to identify market trends and adapt accordingly?	(Wu and Chen, 2010) (Moya et al., 2020) (AFRC, 2021) (Waiyawuththanapoom et al., 2013) (Manotungvorapun and Gerdsri, 2021) (Janssen et al., 2014) (Shum, 2015) (Al-Ashaab et al., 2011) (Yildirim et al., 2022)
5.7.R8	Available Resources	- Have costs for projects, both internal and collaborative been budgeted? - Are innovations accounted for in the budget? - Are innovations and developments accounted for separately in the budget?	(AFRC, 2021) (Wu and Chen, 2010) (Moya et al., 2020) (Yaghoubi et al., 2017) (BSI, 2019)

		- What percentage of the budget is allocated to innovations? - Does the business receive public funding for innovations? - Are relevant resources and equipment available? - What are the employee resources? For example, knowledge, skills, experiences, ideation, risk management - What is the business resources? For example, conflict resolution abilities, processes and processes for decision making	(Janssen et al., 2014) (Enkel et al., 2011) (Al-Ashaab et al., 2011)
5.7.R9	Knowledge Management	- Are there internal innovation capabilities? - Are there knowledge management procedures? - Is there a process for developing and enhancing business knowledge? - Is there a lessons' learnt feedback loop?	(Yaghoubi et al., 2017) (Iddris, 2016) (Waiyawuththanapoom et al., 2013) (BSI, 2019) (Enkel et al., 2011) (Shum, 2015) (Yildirim et al., 2022)
5.7.R10	Reasons for Collaborating	- Is OI included in business strategy to develop a product innovatively? - Is the business externally seeking knowledge and technology about OI? - Is the business periodically seeking OI collaborations? - Are employees incentivised to collaborate externally? Are employees or allocated teams actively seeking OI opportunities and external technologies? - Is there a strategy for product development? - Is there a need for a new project?	(Meina et al., 2018) (AFRC, 2021) (Bevis and Cole, 2010) (Stevens et al., 2009) (BSI, 2019) (Manotungvorapun and Gerdsri, 2021) (Janssen et al., 2014) (Enkel et al., 2011) (Shum, 2015)
5.7.R11	Partner Selection	- Do you trust your collaboration partner? - Are you able to work together on through the project with defined roles and responsibilities? - Have you worked with your partner before? - Are your operations and work styles similar? - Is your partner adaptable to change? - Do you share similar goals with your partner? - Can you agree upon collaboration processes, procedures and IP management? - Does your partner have a track record of OI? - Do you have a deadline? - Are partners selected through a strategic process?	(Manotungvorapun and Gerdsri, 2016) (Lin et al., 2020) (Abbate et al., 2019) (BSI, 2019) (Manotungvorapun and Gerdsri, 2021) (Janssen et al., 2014) (Enkel et al., 2011) (Gribbin et al., 2018)
5.7.R12	IP Management	- Are outputs patented? - What are the boundaries of information and knowledge sharing in OI? - What is the IP management? - Are technologies and patents IP protected? - Is IP management a part of the strategy implemented?	(Wu and Chen, 2010) (Krause and Schutte, 2015) (Uribe-Echeberria et al., 2019) (Meina et al., 2018) (Moya et al., 2020) (BSI, 2019) (Manotungvorapun and Gerdsri, 2021) (Enkel et al., 2011) (Yildirim et al., 2022) (Janssen et al., 2014)
5.7.R13	OI Collaboration Dynamics and Management	- Is the collaboration documented? - Are responsibilities defined and updated frequently? - Does the collaboration have defined procedures, processes and governance? - Are the goals and risks of collaboration identified? - Is there a procedure to report barriers and issues? - Does the RC promote external OI? - Does the RC tend to collaborate? - Does the RC depend on others externally? - Has there been internal developments, such as frameworks or tools to support OI? - Is there a dedicated interface team/individual allocated to the collaboration? - Have resources been assigned? OI Planning and Preparations - Has a strategy been devised? - Have influential factors of OI been identified? - Have roles and responsibilities been developed for OI? - Are there OI procedures and processes? OI Processes	(Uribe-Echeberria et al., 2019) (Meina et al., 2018) (Krause and Schutte, 2015) (AFRC, 2021) (Moya et al., 2020) (Bevis and Cole, 2010) (Abbate et al., 2019) (BSI, 2019) (Manotungvorapun and Gerdsri, 2021) (Janssen et al., 2014) (Enkel et al., 2011) (Gribbin et al., 2018) (Yildirim et al., 2022) (Shum, 2015)

		- Is there an opportunity for idea creation and exploration? - Is there a process for concept development and selection? - Are there R&D and OI management processes? - Are objectives, roles and responsibilities clearly defined? - Are there decision-making processes in place? - Metrics and Assessments of OI - Are there innovation key performance indicators? - Has the business implemented OI metrics? OI Experience - Has the business previously participated in OI? - How experienced is the business in OI? - How experienced is the business in finding a collaborator? - Is the business currently involved in any OI collaborations? - Are business products regularly the output of OIs?	
5.7.R14	Feedback Loop for Development	- Are lessons learnt compiled, tracked and applied? - Are the outputs reviewed and analysed frequently? - Are there channels for feedback and development? - Is there a feedback process from collaborators? - Are there regular reviews of innovation performance? - Are there benchmarks set? - Have metrics been reviewed and improved - Is the project routinely checked?	(Iddris, 2016) (Krause and Schutte, 2015) (Yaghoubi et al., 2017) (Moya et al., 2020) (Enkel et al., 2011) (Bevis and Cole, 2010) (Stevens et al., 2009)

Table 5.7 – Detailed Anatomy of Frameworks Used in Assessing Innovative Readiness in Collaborations, Adapted from (Meina et al., 2018) and (Iddris, 2016)

Prior research has pointed out that directly copying benchmarks or brackets without accounting for the context can have adverse effects (Shum, 2015). Meina et al. (2018) points that the lack of a context scope is still a prevalent issue in literature with the potential for assessment criteria to be disarrayed. Some researchers are compiling metrics, somewhat similar to how this researcher has in Table 5.7, however, this is only a partial representation, and not the final output. Enkel et al. (2011) and Meina et al. (2018) reflected on this and concluded that frameworks should be modularized and tailored to context to avoid exhaustive irrelevant data collection, something noted and not seen applied much in literature.

Another interesting point is the stage in a project lifecycle and the level of involvement that a business wants to enter an collaboration. For example, Piller and Ihl (2009) viewed collaborations as one of three forms, designing for, designing with and designed by the customer (consultancy basis). Another example is innovation intermediaries were found to be most effective in the initial stages of collaboration (Janssen et al., 2014). Most papers seem to report the collaboration throughout a project lifecycle with full involvement in whatever the topic is. Those could be some of the contributing factors to unnecessary data collection. It could be a lack of consideration of business' OI intentions in literature (Meina et al., 2018).

5.7.3. Methodologies and Methods Used

There were two predominant routes of methodologies and methods generally used. Secondary theoretical research was used to conduct literature reviews resulting in the development of a hypothesized conceptual framework or model (Tammela and Salminen, 2016, Wu and Chen, 2010, Krause and Schutte, 2015, Yaghoubi et al., 2017, Moya et al., 2020, Iddris, 2016, Waiyawuththanapoom et al., 2013, Armenakis et al., 1993, Bevis and Cole, 2010). It was also applied alongside a survey method to governing authority's data registers and analysed quantitively through various tools, such as partial least square, structural equation modelling and formative constructs (Uribe-Echeberria et al., 2019, Zhang et al., 2020).

Another predominant route was the use of mixed methods in either an exploratory research or hypothetical-deductive study. This was mainly through case studies, surveys (questionnaires and interviews) and workshop methods (Janssen et al., 2014, Yildirim et al., 2022, Al-Ashaab et al., 2011, Shum, 2015, Enkel et al., 2011, Manotungvorapun and Gerdsri, 2021, Ye et al., 2012, AFRC, 2021, Meina et al., 2018, Emden et al., 2006). Various measurements were used in analysing the results, such as scorecards, Likert scales, weighting factors, multivariate data analysis, decision modelling, radar charts, or qualitatively, through observations and comparative analysis. In support of this route, there have been observations and recommendations made by researchers that surveys and case studies were the methodology of choice in assessing collaborative innovations (Armenakis et al., 1993), Mattes (2011) referenced in Meina et al. (2018). The preferential methods being questionnaires and interviews. An interesting point noted was the methodological choices that Henry Chesbrough, the researcher that coined OI, made when assessing OI, namely, surveys and questionnaires (Chesbrough and Brunswicker, 2014).

These recommendations, alongside the overwhelming use of these methodologies and methods provides a compelling argument to follow suit methodologically in innovation readiness assessments. It may be of interest for researchers to test the efficacies of other methodological choices in OI assessments, but that is beyond the scope of this research.

Chapter 6

Discussion and Assessment Tool Development

6. Discussion and Assessment Tool Development

Chapter Purpose	This chapter sets to discuss the findings from the data collection phase and design an assessment tool that derives from the findings which is tailored to the context.
Chapter Output	This chapter contributes to the fourth research objective This chapter discusses the findings of the literature reviews and identifies a gap in knowledge that ties up with a gap in practice. Furthermore, it develops an assessment tool through the synthesis of relevant literatures and address the problem in practice.

6.1. Discussion of Gaps in Knowledge and Practice and Proposed Assessment Tool

The key theme identified in my findings that provided a basis for the assessment tool was from the preliminary scoping interviews. One of the candidates, Candidate B, identified that businesses were wanting to collaborate with RCs in the context of LW and were making enquiries to them, however they did not entirely understand LW or its application. They had automatically attributed LW to benefiting the product. That is, they were likely thinking along the lines that a product using a lighter and stronger material than the original, such as a composite, would equate to either better performance, higher profits or a more sustainable product. Furthermore, the candidate had pointed out that this was not a one-off case, rather, there was an influx of enquiries. After reviewing the enquiries and probing further with the businesses, they had identified that many of the enquiries were shallow in concept and did not proceed further. This was because little to no prior investigations were conducted by the approaching businesses to justify and validate the need to LW. The candidate's business, an RC, had noted that in some cases the lack of initial analysis had later led to discovering that it was a negative impact to LW, citing higher costs, less sustainability or negligible performance changes to warrant proceeding further. The candidate had further pointed out that this was skewing their results in collaborations due to the ratio of successful collaborations vs. rejected enquiries.

This key theme is complimented by a finding from Tann et al. (2002), where they noted that businesses had been negatively impacted by allocating time and resources to sifting through enquiries to identify potential matches. This could be due to the RC not defining their collaboration scopes clearly and having to individually sift through each case to find projects and businesses that are ready for collaboration (Uribe-Echeberria et al., 2019). Oduro (2020) further compliments this finding and noted that businesses found it difficult to match with collaborators, notably in aligning their resources and management to the collaboration at hand. Oduro went on further to state that businesses needed support in finding a suitable partner, finding that identifying collaborators was adversely affecting the businesses. Oduro (2020) and Wang (2012) added that the matchmaking would need to be incorporate objectives and technological capabilities.

Subsequently, a systematic literature review was conducted for the management and innovation readiness of businesses in LW. No information could be found on LW collaborations and little information was present on the management of LW, where the attributes and frameworks or processes of LW were discussed. This was reviewed, synthesized and discussed in Chapter 3. Therefore, the scope was broadened to consider innovation readiness of businesses in any field, paying attention to the field of manufacturing. Interestingly, there were articles that applied Innovation readiness frameworks to specific contexts, such as sustainability, SMEs, supply chain, UICs, but no innovation readiness framework could be found that had been uniquely tailored to lightweighting contexts. The majority of articles focus on some form of compatibility, but they tended to lean more towards the outcomes at the end of a collaboration or assessing capability/maturity without an industry driven context. One tool was identified, done by the AFRC (2021) for advanced manufacturing, but it did not seem to be in academic literature or peer-reviewed. However, it served a great purpose as an example of what one RC in an advanced manufacturing industry was doing.

There were frameworks for approaching businesses to assess RCs for various reasons, Waiyawuththanapoom et al. (2013) Bevis and Cole (2010) Manotungvorapun and Gerdsri (2016) Manotungvorapun and Gerdsri (2021) to name a few, but frameworks administered by self-intermediating RCs were sparse in literature. Uribe-Echeberria et al. (2019) had done something similar, but the method of data collection was a self-administered survey to a register, rather than to

approaching businesses in industry. Literature does point out to the extensive networking skills of RCs and that they do somewhat intermediate between businesses, though in literature, this was perceived to be more of a tertiary role. This tertiary role of intermediation, and more importantly to this research context, self-intermediation, is not widely discussed in literature.

The lack of an assessment tool identified is the first knowledge gap in literature. This coupled with the pressing need for a tool in industry to aid RC's in sifting out businesses to collaborate with led the author to develop a tailored innovation readiness assessment tool for businesses collaborating in LW. This assessment tool requires a business to have two needs, a need to LW and seeking support from an RC in LW. This assessment tool would be applied by the RC towards an approaching business, who is acting as a self-intermediary, and would identify their innovation readiness to collaborate by asking targeted questions specific to the context of LW and innovation readiness (Janssen et al., 2014).

	Findings	**Gap in Knowledge / Practice**
Preliminary Scoping interviews	- Businesses not entirely understanding LW or its application - Businesses have shallow enquiries - Many businesses are making enquiries without initial analysis of LW - RCs have their KPIs skewed because of high ratio of rejected enquired	- No assessment tool to aid businesses/RCs in sifting out potential collaborators in LW
Literature Review	- Tann et al. (2002) ties in with the preliminary scoping interviews that businesses have been negatively impacted by influx of enquiries - RCs are potentially not defining their collaboration scopes (Uribe-Echeberria et al., 2019) - Businesses need support to as they are finding it hard to match with collaborators (Oduro, 2020) - frameworks administered by self-intermediating RCs were sparse in literature - Context driven frameworks to target OI collaborations were supported (Fisher and Qualls, 2018)	- No suitable innovation readiness assessment tool identified in academic literature to aid and guide businesses/RC collaborating in LW.

Table 6.1 – Summarised Findings and Gaps in Knowledge/Practice

Fisher and Qualls (2018) had supported providing context to a framework so that a more targeted OI strategy can be devised and implemented. This assessment tool would assess an approaching business' readiness to innovatively collaborate in LW. The first purpose is that the innovation readiness assessment tool would serve as a resource to an RC, aiding them to sift out and identify potential collaborators more efficiently and effectively. The second purpose is that it would help approaching businesses identify their readiness levels to collaborate in LW, pointing out how they should be approaching LW and factors that they would need to address and consider.

The development and application of this assessment tool is complex in nature. There are many variables to consider that can cause confusion, uncertainty and irrelevant data collection. This was approached addressed this through two methods. Firstly, in literature, many authors collated frameworks with exhaustive parameters. It is a compelling argument to collate various innovation readiness parameters and tailor them towards the current context as that which is relevant should be considered. Other irrelevant parameters bear little to no weighting in the analysis of the collaboration and should not be applied, as it unnecessarily exhausts the data collection phase, which the can be seen as a potential deterrent.

Secondly, is the selection of parameters. This was implemented through adapting a decision making process, inspired by Yildirim et al. (2022). This process, would act in a flowchart type manner, with specifics of each scenario inputted by the approaching business in the type of collaboration they want to engage in. The boundaries, defined by the scenario specifics would apply the relevant LW parameters, thus utilise key parameters and sift out irrelevant data collection. This would create an adaptable self-assessment tool to the LW support that a business requires.

6.2. Assessment Tool Development

The main components of the assessment tool structure follow similar patterns to Zhang et al. (2020) and Emden et al. (2006). Zhang et al (2020) breaks down green innovation readiness through the technological, organisational and environmental readiness and Emden et al. (2006) pointed to not just having a technological alignment, but having strategic and relational alignments also. The proposed assessment tool consists of three sections. Each section aims to identify different aspects of the collaboration. The first section seeks to determine the nature of the LW project, including the project scope, knowledge base, drivers, and desired outcomes. The second section reviews the different pillars of LW, and identifies key elements of each pillar that contribute towards the business' readiness in that respect. This section is dependent on the first section, where the selection of certain answers will establish boundaries of the collaboration and determine the next line of questioning, which are tailored to these boundaries. That is, only the relevant pillars are answered. For example, if an approaching business is looking for support on the design optimisation side of LW, the user would answer the design optimisation specifics section only. The third section reviews other innovation readiness parameters relevant to the collaboration which will be detailed in Section 6.2.3.

The assessment tool is a self-assessment where the questions are predominantly set in a Yes/No manner with some options to clarify further and some questions allowing multiple selections. This is to reduce the exhaustiveness of the assessment tool, guide the approaching business and give the RC an indication and relevant breakdown of how ready the business is to LW, and how they can target their support more effectively and efficiently. The approaching business might not know some of the answers, however, it gives the approaching business an opportunity to review itself prior to the potential collaboration. Furthermore, the assessment tool aims to get the conversation going by informing the approaching business of the LW collaboration process and subsequently, the RC's expectations. Table 6.2 below denotes the overview of the proposed assessment tool with the following sections reviewing each part of the assessment tool in detail.

Readiness	Level 1	Level 2
Project Scope Readiness	Project Overview	- Drivers - Targets - Market Awareness - Timeline - Finance - Possible Solutions - Support Sought from RC - Outputs
LW Specific Readiness	Design Optimisation Specifics	- Resources - Subject Knowledge - Operational and Strategic Management - Preparation - Holistic Considerations - Regulatory Compliance
	Materials Specifics	- Material Utilisation - Material Substitution - Operational and Strategic Management - Supply Chain - Material Development - Holistic Considerations - Regulatory Compliance
	Manufacturing Specifics	- Holistic Considerations - Available Resources - Manufacturing Utilisation - Manufacturing Substitution - Manufacturing Development - Regulatory Compliance
Innovation Readiness	Innovation Readiness Specifics	- Collaboration Need - Operational and Strategic Management - Resource Allocation - Senior Management Support - IP Management - Communication - LW Consideration - Marketing - Training - Feedback

Table 6.2 – Proposed Assessment Tool – Overview

6.2.1. Stage 1 of Assessment Tool - Project Scope Readiness

The initial section, detailed in Table 6.3, has several elements to it and was devised to identify relevant key parameters of an approaching business. These parameters include drivers, targets, the stages of LW support sought after of the RC, possible solutions, timeline/budget considerations, knowledge and innovation considerations. This section derives from the outputs of the literature reviews conducted in chapters 5 and 3, where the questions merge LW characteristics, and various influential factors of innovation readiness in collaborations.

The first five questions of this stage query the driving factors and targets of an approaching business wanting to LW and match them with those established and identified in LW. These questions are considered highly relevant as it identifies if a business has an applicable driver or target that would require the use of LW. There may be other drivers and targets, with the questions providing an option to specify further, but those that were predominant in literature were noted. This allows the RC to analyse the relevance of the driver or target, and mark it accordingly. The fifth question queries the market awareness of the business and gives a good indication as to whether or not value has been attributed to this project, and possibly, innovation.

Questions 6 and 7 seek to identify if the business has prepared themselves with a timeline and budget of achieving a LW solution in the collaboration. Questions 8 to 11 address how they want to achieve their LW goal and the stages of support sought after by the business. The answers selected in questions 11 will determine in the LW specific readiness section of the assessment tool what sections to answer. Questions 12 to 15 identify if they have a LW concept and aims to find if they have linked the concept to their goals and drivers.

This section has been tailored to the context and links the application of LW to innovation and collaboration readiness parameters mentioned in Appendix 3 and influential factors mentioned in Chapter 5.4. Namely, it identifies if preparations have been conducted with allocated resources and defined timelines. These points indicate a commitment towards the collaboration, the value that they place in the project and the operational and strategic management of their collaborative projects.

#	Stage 1 of Assessment tool - Project Scope Readiness Questions	Purpose
1	Have you identified what drove your need to implement LW?	Self-awareness of driver
	Question Importance: A leading question to find out if the business has identified LW drivers. Businesses not identifying drivers to LW may have adverse effects. **Link to Literature**: (Witik et al., 2011, Kaspar and Vielhaber, 2016)	
2	If yes, Is the driver any of the below? a. Functionality b. Profitability c. Sustainability d. Other. Please Specify _____	Identify driver
	Question Importance: In Chapter 3.1, the literature identified that the reason to LW is usually one of these points, and that identifying the driver will aid design priorities. **Link to Literature**: (Zhu et al., 2018, Fan and Njuguna, 2016, Czerwinski, 2021)	
3	Have you identified the goal(s) to implementing LW?	Self-awareness of target
	Question Importance: Tying up LW application to goals. Identifying priorities dictating innovation and collaboration direction. **Link to Literature**: (Witik et al., 2011, Zhu et al., 2018, Fan and Njuguna, 2016, Czerwinski, 2021, Kaspar and Vielhaber, 2016)	
4	If yes, Is it any of the below? (Multiple allowed) a. Financial target b. Sustainability target c. Performance target d. Other. Please Specify _____	Identify target
	Question Importance: Similar to Question 3	
5	Has this goal or target been linked to market research or customer feedback?	Market awareness
	Question Importance: There needs to be a market for this LW, whether this has come from market research or customer feedback. **Link to Literature**: Table 5.7 R7	
6	Do you have a timeline for this project with identified milestones? If yes, please specify the timeline? _____	Timeline
	Question Importance: the timescale would need to be considered as to finding an availability of when both partners are able to conduct the project. **Link to Literature**: (Bertello et al., 2021), Table 3.1.R2, Table 5.4 R9.	
7	Have you allocated a sufficient budget to cover the project and collaboration? If yes, please specify the allocated budget _____	Finance

	Question Importance: the cost and available resources would need to be considered. **Link to Literature**: (Bertello et al., 2021), Table 5.3 R6, Table 5.4 R19, Table 5.4 R20, Table 5.7 R8.	
8	Do you know how you want to achieve your LW target?	Proposed solution
	Question Importance: Identifying if the business already has a LW plan. This indicates to the RC the level and type of support that they will be providing. This may help RCs to sift to find suitable partners as they might only have the capacity to deal with businesses that need a certain type of support (unavailable resources). **Link to Literature**: Table 5.4 R21	
9	If yes, is it through any of the below? (Multiple allowed) a. Design Optimisation b. Material selection or replacement c. Change in manufacturing processes d. Other. Please specify _____	Solution field
	Question Importance: Identifying how they want to implement LW changes. **Link to Literature**: Chapter 3.2, literature predominantly agrees that these are the main pillars of LW in which changes would be made.	
10	Are you needing support from the RC in any of these aspects? If no, please specify what support you require _____	Support sought from RC Would contact RC if no
	Question Importance: This question directly indicates what support they require from the RC, identifying the need to collaborate. Identifying their abilities will help the RC tailor their support. **Link to Literature**: (Lin and Wei, 2018), Table 5.4 R6.	
11	If yes, which stages? (Multiple allowed) a. Design Optimisation b. Material selection or replacement c. Change in manufacturing processes d. Additional aspects that you would like the RC to consider _____	Any ones selected here will be for next stage. Additional support will be need to be individually reviewed by the RC
	Question Importance: This question will open up further questions in stage 2 of the assessment tool depending on what they answer. It is a follow up question from questions 9 and 10.	
12	Do you have a LW concept?	If yes, answer selected questions in respective areas below
	Question Importance: A probing question to identify how the RC can better tailor their support and have a starting point to work from. **Link to Literature**: (Lin and Wei, 2018), Table 5.4 R6.	

13	If yes to Question 12, and a financial target has been selected, has the proposed design been analysed to be financially viable to the business?	Output: Finance Innovation
	Question Importance: The application of LW needs to be verified against the target. **Link to Literature**: (Witik et al., 2011, Herrmann et al., 2018)	
14	If yes to Question 12 and a sustainability target has been selected, has the proposed concept been analysed through a Lifecycle assessment to be sustainable?	Output: Sustainability Innovation
	Question Importance: The application of LW needs to be verified against the target. If sustainability is the key driver or is being considered, then LCA should be also considered. **Link to Literature**: (Witik et al., 2011, Herrmann et al., 2018, Kaspar and Vielhaber, 2016)	
15	If yes to Question 12 and a performance target has been selected, Does the proposed design have improved performance characteristics?	Output: Performance Innovation
	Question Importance: The application of LW needs to be verified against the target. **Link to Literature**: (Witik et al., 2011, Herrmann et al., 2018)	

Table 6.3 – Stage 1 of Assessment Tool – Project Scope Readiness

6.2.2. Stage 2 of Assessment Tool - LW Specific Readiness

This section focuses on the LW specific readiness aspects of the collaboration. Similar to the above project scope readiness section, this section is tailored to the context of LW. There are 3 components to this section, each looking at the three pillars of LW in the order of design optimisation, materials selection and manufacturing processes. Each section will only be answered if the business is seeking support from the RC in that component, which can be found at Question 11. This allows for specific LW to be considered if the business is only seeking support in one or more aspect of LW. Additionally, each section is reviewed holistically, considering the other pillars of LW for each respective application.

Each component starts with a line of questioning with respect to its own specific field. They address relevant resources, training, considerations and the use of current methods vs. new pre-established methods vs. developing new methods. They all have a common thread between as they are linked and

point to LW readiness. The similarities look at possible solutions being questioned for their viability, and this is primarily indicated through linking outputs to the targets and drivers, namely, financial viability, sustainability and performance indications. Furthermore, the viability is indicated through the potential concepts being measured against the holistic considerations of other LW pillars respectively. This creates an awareness of the comprehensive nature of LW. Each section questions the planning and preparations involved, seeing if they have a possible solution, each followed by further questioning to see if their concepts have considered compliance, regulatory and standard adherence as this was a major concern identified in the interviews and literature.

This section addresses many elements in innovation readiness and complements it through its application, namely, operational and strategic management, resources, training, relevant subject knowledge and employee capabilities. This allows for the following section to be more specific to address other relevant innovation readiness parameters that identified in literature (Enkel et al., 2011). Table 6.4, Table 6.5 and Table 6.6 detail the LW specific readiness section of the assessment tool.

#	Stage 2a of Assessment tool - Design Optimisation Readiness Questions	Purpose
	For question 11, if answer "a" was selected, then answer the following questions	**Pillar: Design Optimisation**
16	Do you have readily available technology and software for optimizing designs and topologies?	Available Resources
	Question Importance: In order to optimize a design, technology and software is required. **Link to Literature**: (Roy et al., 2008, Le Duigou et al., 2016), Table 3.1 R5	
17	Do you have staff experienced and trained in optimizing and analysing designs and topologies?	Relevant Subject Knowledge
	Question Importance: Lack of training was identified as a barrier to optimizing and analysing designs. Essential for serious based businesses to use these tools **Link to Literature**: Table 3.1 R7, Table 5.4 R1, Table 5.4 R12	
18	Do you have processes or procedures for optimizing designs and topologies?	Operational and Strategic Management
	Question Importance: Identifying if the business has relevant processes in place. It also raises awareness to the RC that the business has internal processes to adhere to. **Link to Literature**: Table 3.1 R8	
19	Have you identified constraints or boundaries for the LW project? Such as spacing, connections, other components etc.	Holistic: Boundaries
	Question Importance: There are LW projects that have many constraints to be considered. (E.g. a wing component will have weight, strength and sizing constraints) this is to find out if the business has identified them. **Link to Literature**, (Kaspar and Vielhaber, 2016, Herrmann et al., 2018, Zhu et al., 2018)	
20	Have you considered what materials to use?	Holistic: Material Consideration
	Question Importance: LW is generally a holistic process and material consideration is required. **Link to Literature**: (Zhu et al., 2018, Kaspar and Vielhaber, 2016)	
21	Have you considered the ability to manufacture it with the selected materials?	Holistic: Manufacturing consideration
	Question Importance: LW is generally a holistic process and manufacturing consideration is required. **Link to Literature**: (Zhu et al., 2018, Kaspar and Vielhaber, 2016)	
22	If there is a design concept, does it meet standards and requirements?	Regulatory Compliance
	Question Importance: Meeting design requirements may pose a challenge when attempting to LW **Link to Literature:** Table 3.1 R8	

Table 6.4 – Stage 2a of Assessment tool – Design Optimisation Specifics

#	Stage 2b of Assessment tool - Materials Selection Readiness Questions	Purpose
	For question 11, if answer "b" was selected, then answer the following questions	**Pillar: Materials Selection**
23	Have you tried utilizing the current materials used?	Material Utilisation
	Question Importance: Literature has indicated that before using newer materials, you should attempt utilizing current materials. **Link to Literature**: (Tempelman, 2014)	
24	Do you have a justified need to substituting materials in the design?	Material Substitution
	Question Importance: Similar to Question 23 **Link to Literature**: (Tempelman, 2014)	
25	Do you have a process or procedure for selecting a new material?	Operational and Strategic Management
	Question Importance: Several articles indicate a process for selecting a new material. **Link to Literature**: (Czerwinski, 2021, Kaspar et al., 2018, Kaspar and Vielhaber, 2016, Tempelman, 2014)	
26	Are the materials or material compositions readily available?	Supply chain
	Question Importance: The availability of materials needs to be considered.	
27	Do you need to develop a new material?	Material Development
	Question Importance: If there is no relevant material that they have identified, perhaps a bespoke material may be required.	
28	Can the selected material be shaped to the desired topology through an approved manufacturing method?	Holistic: Manufacturing and Design Optimisation Consideration
	Question Importance: The selection of materials for each application should not be independent of designing and available manufacturing. **Link to Literature**: (Mouritz, 2012, James, 2016, Tempelman, 2014, Kaspar et al., 2018, Mallick, 2010).	
29	Is the material selected fit for purpose?	Regulatory Compliance
	Question Importance: The material needs to be suitable for operation and approved for use by the end client and regulatory authorities. **Link to Literature**: Table 3.1 R8	

Table 6.5 – Stage 2b of Assessment Tool – Materials Specifics

#	Stage 2c of Assessment tool - Manufacturing Readiness Questions	Purpose
	For question 11, if answer "c" was selected, then answer the following questions	**Pillar: Manufacturing Processes**
30	Can the design be physically manufactured with the given materials?	Holistic: Design Optimisation and Material consideration
	Question Importance: The selection of materials for each application should not be independent of designing and available manufacturing. **Link to Literature**: (Mouritz, 2012, James, 2016, Tempelman, 2014, Kaspar et al., 2018, Mallick, 2010).	
31	Do you have the necessary manufacturing tools and processes to build the proposed concept?	Available Resources
	Question Importance: This question identifies available resources and potential method of support that the RC can offer. **Link to Literature**: (Zhu et al., 2018, Roy et al., 2008)	
32	If no to Question 31, have you tried optimizing the design to use the available manufacturing methods?	Manufacturing Utilisation
	Question Importance: Prior to using new methods, have the current options been exhausted? **Link to Literature**: (Tempelman, 2014, Roy et al., 2008, Zhu et al., 2018)	
33	Do you need to employ a new manufacturing method that is available in the market?	Manufacturing Substitution
	Question Importance: If the design cannot be manufactured with the current methods, have they found another viable method in the market? **Link to Literature**: (Koch et al., 2016, Roy et al., 2008)	
34	If yes to the above, has this new manufacturing method been identified and analysed to be profitable/functional/sustainable, depending on targets identified?	Output: Targets Operational and Strategic Management Preparation
	Question Importance: Have they researched the new manufacturing method. This illustrates a more detailed readiness level if they have. **Link to Literature**: Table 3.1 R4, Table 3.1 R10	
35	Do you need to develop a new manufacturing method?	Manufacturing Development
	Question Importance: Through process of elimination, the last remaining stage of identifying a manufacturing method is do they need to create a one? **Link to Literature**: Table 3.1 R4	
36	If yes to Question 35, Is the manufacturing method approved for use by the end client and by regulatory authorities?	Regulatory Compliance
	Question Importance: Have they gotten to the stage of confirming compliance and third-party approval? **Link to Literature**: Table 3.1 R8	

Table 6.6 – Stage 2c of Assessment Tool – Manufacturing Specifics

6.2.3. Stage 3 of Assessment Tool - Innovation and Collaboration Readiness

The last section to the assessment tool focuses on the innovation readiness of the business. Relevant innovation readiness parameters indicated in literature that were not yet applied in the in the previous sections are accounted for here. They are collaboration need, senior management support, operations and strategic management, resource allocation, communication, LW consideration, training, marketing and feedback. These sections were selected and the questions formulated with respect to the contexts of both LW and a collaboration between an RC and a business. For example, question 44 focuses more on the LW consideration of the business, identifying if space is provided for iterative conditions, with sufficient resources allocated and allowing mistakes to be made with the focus of identifying barriers and addressing them. These are all elements in which LW is prevalent in a business and preparations that an approaching business should consider to become more ready.

The sharing, handling and communication of intellectual property was highly relevant in literature and considered for this assessment tool. Questions 44 and 47 look at channels of communication and feedback. Question 42 looks at the IP management. Many assessment tools in literature review IP management in depth. This assessment tool considers two main aspects which were seen to be the underlying tones of collaborations, that is, does the approaching business have an IP management in place and are they willing to work with the RC to reach an agreement for mutual IP management? Questions are also directed both internally and externally, where the internal questions are similar to what was mentioned in previous sections but for different aspects of the collaboration, while the external questions predominantly look at the collaboration dynamics and the business's preparation for this. Table 6.7 details Section 3 of the assessment tool.

#	Stage 3 of Assessment tool – Innovation Readiness Questions	Purpose
37	Has the sourcing of external support been justified through internal review?	Collaboration Need
	Question Importance: This directly addresses that a need to collaborate has been identified and justified by the business. **Link to Literature**: Table 5.4 R17, Table 5.4 R21	
38	Does the business have a clear and concise strategy for LW developments?	Operations and Strategic Management
	Question Importance: Do they understand the beneficial reason to LW and how they can tie that to their targets? **Link to Literature**: (Tempelman, 2014, Zhu et al., 2018, Roy et al., 2008)	
39	Does the business have established processes or procedures for collaborating?	Operational and Strategic Management
	Question Importance: Several researchers correlate poor internal processes for collaboration to negative outcomes. **Link to Literature**: Table 5.3 R7, Table 5.3 R3	
40	Has the business allocated sufficient resources, including employees, time, funding, and technologies to R&D for this project?	Resource Allocation
	Question Importance: Several frameworks signify the importance of sufficient resources allocated. **Link to Literature**: (Enkel et al., 2011, Manotungvorapun and Gerdsri, 2016, Yaghoubi et al., 2017, AFRC, 2021), Table 5.4 R20, Table 5.7 R8.	
41	Is senior management supportive and involved in collaborations?	Senior Management Support
	Question Importance: The support of senior management can help establish and promote successful collaborations with many researchers citing this as important **Link to Literature**: (Uribe-Echeberria et al., 2019), Table 5.4 R4	
42	The RC has certain IP management procedures, are you willing to work with the RC to identify a suitable IP management for both parties?	IP Management
	Question Importance: An agreement needs to be made for IP management, and that for a collaborative endeavour, both parties need to gain from it. **Link to Literature**: Table 5.4 R7	
43	Are formal communication channels set up for external collaborations for relevant information being shared? (E.g., established processes, points of contact, working within IP)	Communication
	Question Importance: Designated and relevant points of contact are required for the project to be collaborative and contributory from each party. Furthermore, relevant information must be shared in accordance with the IP agreements. **Link to Literature**: Table 5.4 R14	

44	Will the business allow flexibility to manage an arduous trial and error process during design? (The process of utilizing, substituting and developing methods is iterative and planning is required (Note: Project scope will be considered)	LW Consideration
	Question Importance: LW is an iterative process with many trials and errors. This point is highly relevant in identifying a suitable partner. **Link to Literature**: (Tempelman, 2014, Zhu et al., 2018, Roy et al., 2008), Table 3.1 R2	
45	Does the business identify market trends and adapt accordingly?	Marketing
	Question Importance: Communication between the marketing team and other internal departments is important to accurately reflect both the needs of the market and the capabilities of the business can positively impact the collaboration. **Link to Literature**: Table 5.3 R4, Table 5.4 R13	
46	Is there a skills matrix for employees in LW and collaborations?	Training
	Question Importance: This establishes not only an employee's current skills, but a development chart to which employees can work towards improving their skills in both LW and collaborations. **Link to Literature**: Table 3.1 R7, Table 5.2 R3, Table 5.4 R12	
47	Is there a procedure to report barriers and issues in collaborations?	Feedback
	Question Importance: Feedback for tracking performance, barriers and enablers can help enhance the collaboration. **Link to Literature**: Table 5.4 R15, Table 5.7 R14, Table 5.7 R9	

Table 6.7 – Stage 3 of Assessment Tool – Innovation Readiness Specifics

6.2.4. Output

All questions derive from the literature reviews and hold relevance towards both LW and innovation readiness in collaborations in the context of RC/approaching business. The questions within the assessment tool are predominantly framed as yes/no questions to see if the business has complied with each criterion, with the 'Yes' answers being attributed to a positive reflection on the business. Some of the questions give an opportunity for the candidate to elaborate further, whether it be for an option not accounted for that may provide further relevant insight to the RC or for a specific answer that the framed question cannot answer, such as the allocated budget and timescale, where the

answer is subjective to each business. This allows the RC to review any specifics that are out with the norm or consider if the scope of the project is reasonable or achievable.

Table 6.8 denotes a detailed scoring for the assessment tool. Each question is shown how to be scored and has a weighting of 1 point. There are some questions that are follow-on questions. These follow-on questions are only considered in the marking if they are applicable. For example, if question 31 is "No", then question 32 is to be skipped and is not considered in the marking.

There are 3 stages in this assessment tool consisting of 5 different sections which are colour coded below. Stages 1 and 3 are to answered as part of the assessment tool. Stages 2a, 2b and 2c are only applicable if they have been selected in Question 11. For example, if the business only selects "Design Optimisation" as a target in Question 11, then only Stage 2a is to be considered from the 3 sections in Stage 2. Stage 2b and 2c are not considered. And likewise for other scenarios. The final scoring depends on the total number of questions considered.

There are 3 ways look at the output of this assessment tool,

1- A full score comparison: Depending on the answers selected, the total points awarded are compared to the total possible score. The higher the score, the more ready a business is to collaborate. For example, Business X with a score of 35/47 is more ready to collaborate than Business Y with a score of 22/47.
2- Stage by stage scoring: Each stage can be scored individually and assessed for how ready they are in that stage. For example, A business might have scored 2/7 in Stage 2a, 5/7 in Stage 2b, and 5/7 in Stage 2c. This would indicate that the business is more ready in materials and manufacturing than in design optimisation. This would help identify more quickly that the support likely required is tailored towards design optimisation.
3- A detailed review of the business's answers: Each question is reviewed carefully to identify the scope of the project and support required in the collaboration. This review takes the prior two scorings to a detailed level where an understanding is gained of the project scope and business capabilities. For example, the business might have great collaboration capabilities, but the project timescale is too short and the budget is too low.

S	Q	Points	S	Q	Points
Stage 1	1	If “Yes”, award 1 point	Stage 2b	23	If “Yes”, award 1 point
	2	If “No” to Q1, do not consider If “Yes” to Q1” and driver noted, award 1 point		24	If “Yes”, award 1 point
	3	If “Yes”, award 1 point		25	If “Yes”, award 1 point
	4	If “No” to Q3, do not consider If “Yes” to Q3” and target noted, award 1 point		26	If “Yes”, award 1 point
	5	If “Yes”, award 1 point		27	If “Yes”, award 1 point
	6	If “Yes”, award 1 point		28	If “Yes”, award 1 point
	7	If “Yes”, award 1 point		29	If “Yes”, award 1 point
	8	If “Yes”, award 1 point	Stage 2c	30	If “Yes”, award 1 point
	9	If “No” to Q8, do not consider If “Yes” to Q8” and target noted, award 1 point		31	If “Yes”, award 1 point
	10	If “Yes”, 1 point If “No” and reasonable support noted, award 1 point		32	If “No” to Q31, do not consider If “Yes” to Q31” and “Yes” to this question, award 1 point
	11	**If “No” to Q10, do not consider If “Yes” to Q10” and target(s) noted, award 1 point**		33	If “Yes”, award 1 point
	12	If “Yes”, award 1 point		34	If “No” to Q33, do not consider If “Yes” to Q33” and “Yes” to this question, award 1 point
	13	If “No” to Q12, do not consider If “Yes” to Q12” and target noted, award 1 point		35	If “Yes”, award 1 point
	14	If “No” to Q12, do not consider If “Yes” to Q12” and target noted, award 1 point		36	If “No” to Q35, do not consider If “Yes” to Q35” and “Yes” to this question, award 1 point
	15	If “No” to Q12, do not consider If “Yes” to Q12” and target noted, award 1 point	Stage 3	37	If “Yes”, award 1 point
Stage 2a	16	If “Yes”, award 1 point		38	If “Yes”, award 1 point
	17	If “Yes”, award 1 point		39	If “Yes”, award 1 point
	18	If “Yes”, award 1 point		40	If “Yes”, award 1 point
	19	If “Yes”, award 1 point		41	If “Yes”, award 1 point
	20	If “Yes”, award 1 point		42	If “Yes”, award 1 point
	21	If “Yes”, award 1 point		43	If “Yes”, award 1 point
	22	If “Yes”, award 1 point		44	If “Yes”, award 1 point
				45	If “Yes”, award 1 point
				46	If “Yes”, award 1 point
				47	If “Yes”, award 1 point

Table 6.8 – Assessment Tool Scoring

A key point to understand for this assessment tool is that there is no minimum score of criteria to collaborate. There are too many external variables that are subjective to the RC. For example, An RC might be too busy to allocate sufficient resources for a semi ready-to-collaborate business, or another RC might be out of work and willing to work with a low-readiness business.

The output initiates and directs the conversation between the RC and approaching business. It illustrates a local and global representation of the business's standing. Each question represents a purpose and can aid the RC in guiding a conversation between them and tailoring their support to the business. On a global point of view, it could allow for the business to decide a minimum score of acceptability. It is up to each RC to determine what characteristics they accept as a minimum requirement before collaborating further with them. For example, if the approaching business has allocated an insufficient budget or a seemingly unrealistic timeline, or the output is indicating that the concept lacks depth and thought, the RC can point this out to the approaching business prior to further consideration. This gives the RC a quick and efficient way to assess business and potentially set assessment boundaries in advance, where if a result is below the target grade, an automatic response can be provided to review certain aspects prior to further collaboration, in accordance with the needs of the RC.

Chapter 7

Conclusions

7. Conclusions

This section will critically review and discuss the research objectives, the implications of the findings, the strengths and limitations of the assessment tool, final conclusions, contributions as well as discuss future research avenues.

7.1. A Critical Review of the Research Objectives

There were 4 research objectives that this research set out to achieve,

1. Identify the management aspects of LW, it's components, influential factors and the frameworks used LW as literature has a predominant technical view on LW. This objective was successfully achieved through Chapter 3. The context of LW is critically reviewed, with unique attributes, types, frameworks and influential factors. Literature generally agrees that LW consists of three main pillars holistically interlinked, design optimisation, materials selection and manufacturing processes. No articles were identified by the author that sought the process of collaborating with an external partner seeking support in lightweighting.
2. Identify a relevant and contemporary issue in industry on the management of lightweighting and find out how businesses manage lightweighting. This objective was achieved through the preliminary scoping interviews with 4 candidates from industry. The candidates discussed aspects to managing lightweighting and noted relevant industry issues and potential topics for research, with a gap in practice being the current topic of this research originating from these interviews. The preliminary scoping interviews also identified a practice being used in industry that the author could not find attributed to LW in literature and is a direct contribution to knowledge. Detailed in Chapter 3.3, Indirect LW is a technique that utilizes all the aspects of LW, but the final objective is to achieve a target weight goal that is not necessarily a lighter weight goal. This is due to the driving factor of pre-established design constraints. While the concept is subject to peer review for acceptance, this technique should be considered an indirect form of LW.
3. Exploring linkages between businesses/RCs collaborating together and innovation readiness tools, identifying influential factors and assessment tools used in literature. This research objective was achieved through a systematic literature review in Chapter 5. The review covered RCs, discussing

the roles services, services and influential factors for RCs. It also covered collaboration dynamics between RCs and businesses, looking at motives and influential factors and it finally reviewed the innovation readiness tools and frameworks used in literature. There were frameworks that had been tailored to specific contexts, such as sustainability, SMEs, supply chain, but the author could not find one uniquely tailored to the context of lightweighting. The AFRC (2021) did create a tool for advanced manufacturing, however, it was not found to be peer reviewed or in academic literature. The self-intermediation of RCs was perceived to be a tertiary role in literature. Frameworks administered by self-intermediating RCs was not widely discussed. Uribe-Echeberria et al. (2019) did touch on the point, however, the methodology was a self-administered survey to a register, rather than a framework that was to be applied to an active context of approaching businesses.

4. Create an assessment tool through the synthesis of relevant literatures that would address the problem in practice. The last research objective was achieved where an assessment tool was developed in Chapter 6 through a synthesis of literature reviews of Chapters 3 and 5.

As previously mentioned, it was a challenge for the author to find information on the subject as the research is context specific. The context included several parts, collaborations between RCs and businesses, innovation readiness and LW. Numerous times during literature searches, there were no relevant results. The author addressed this challenge through three ways. Firstly, the use of preliminary scoping interviews to find data directly from industry. Secondly, getting the Faculty Librarian to verify the construct of the SLR in database searches, methodologies, terms and other aspects. Thirdly, by expanding the scope of each term and widening the search terms to find relevant fields, such as the manufacturing industry, or University-Industry Collaborations (UIC). For example, the term “innovation readiness” is not as widely used in literature as open innovation, or maturity/capability frameworks, which is why the author accounted for these other terms as they are closely interlinked. Chapter 5.1 details the multiple terms used to for each context and the multiple cross-searches conducted with the term brackets.

7.2. Implications of Findings

The research contributes both academically and practically. It contributes to knowledge through a niche field where practical concerns have been noted and not addressed in literature. The literature advances theory by creating a new research area at the cross section of lightweighting, RC/business collaborations and innovation readiness assessment tools. It directly contributes to these 3 academic fields, both individually as a further development in the respective field and combined as a niche subject area. No assessment tool combining these fields were found and therefore, it directly advances theory by introducing this new assessment tool.

A further contribution is that this assessment tool specifically focuses on the preliminary stages of LW and expands on motivations and considerations that businesses have made in their attempt to LW prior to collaboration. Most LW frameworks/tools available in literature discuss the start to end process of LW to a component or system (Czerwinski, 2021, Kaspar and Vielhaber, 2016), (Krause, 2012) referenced in (Kaspar and Vielhaber, 2016), (Ellenrieder et al., 2013) referenced in (Kaspar and Vielhaber, 2016).

Another theoretical contribution is that the research acts as a milestone to possible future research directions. Such as,

- Applying the assessment tool and support it with the use of case studies. Primary data can be collected to review the state of innovation readiness of businesses and RCs collaborating in LW and the efficacy of the tool.
- Indirect lightweighting. This subject, discussed in Chapter 3.3.2, is a concept that was not found in literature and further research can look into its application and use.
- Can the readiness of one collaborator influence the readiness of the other? If so, to what degree and with how many additional resources?" The varying levels of input an RC needs to make to support varying levels of approaching business' readiness can prove useful to build the efficiencies of RCs and develop internal management.
- Study the differences in expectations, capabilities and needs between approaching businesses and RCs. As there is a collaborative effort by both parties to innovate, it is can be seen to be necessary to understand the standings and expectations of each party to build a more realistic picture of

what collaborative interactions would look like and a further understanding of the capacity to which the RCs can support businesses.

- Comparisons of the researcher determining readiness vs RCs determining readiness. Each RC would approach businesses in their own way and studying the effect and differences that a researcher would have vs RCs could give insight to practical vs theoretical considerations.

Practically speaking, the research directly addresses an issue occurring in industry. That is, research centres are struggling to sift out between businesses that are ready to innovate and collaborate in LW and businesses that have misconceptions in the application of LW. Practitioners can directly use this tool to aid them in not only identifying potential collaborators but educating them in the process of the boundaries of the collaboration, with key points being highlighted.

For RCs that LW, RCs should be able to sift out more easily potential LW collaborators by determining their level of readiness to innovate and collaborate. RCs should also identify what a business thinks LW will do to their project to determine the viability of collaboration. For businesses seeking to collaborate with RCs in LW, businesses should review the assessment tool and determine their own readiness in each area. They should understand that LW does not directly equate to a better product and that there should be a purpose that shows LW will benefit the product if even at a conceptual level.

7.3. Strengths and Limitations of the Assessment Tool

There are many aspects to the proposed assessment tool in Chapter 6 that are strengths that serve both the context and each sub-context separately. Decisions had to be made to consider what the design would be, the user interface, the style of questioning, what questions need to be asked and what didn't need to be. The following section will review and discuss in detail the strengths and limitations of the assessment tool.

7.3.1. Strengths

An assessment tool is proposed that combines the characteristic elements of collaborative innovations and LW. To establish boundary conditions for this assessment tool, the context, derived from the preliminary scoping interviews and Tann et al. (2002), is defined as an RC receiving numerous collaboration-based enquiries from businesses wanting to LW.

A critical review of this research is little supporting evidence to use the context of businesses and RCs because RCs have been overwhelmed by the number of enquiries. Candidate B in industry pointed out this issue which one older paper was found supporting this (Tann et al., 2002). The candidate did stress the urgency and relevancy of this issue, and it was very compelling due to the manner, emphasis, tone and body language used. This has been added to the use of this context and the likelihood of this being a common issue by noting some interesting and applicable points.

1. LW is closely linked to sustainability, and sustainability is gaining rapid attention due to government initiatives, legislations and a global movement to be more sustainably responsible.
2. LW is also a technique used to enhance performance and profits, both highly desirable features and drivers for businesses.

These two observations are seen to be drivers pushing many businesses to consider the use of LW in their processes. However, LW is an advanced technique that requires training and is a field subject to misconceptions, either that is equated to be automatically better or it is the use of advanced materials or composites. With the lack of training, it can be reasonably assumed that businesses will seek external support to apply LW. Some of these avenues are out with the scope of this research, but a popular avenue is businesses enquiring for support from RCs. This line of thought is seen to be a logical reasoning, enough to support using this context.

LW is an advanced application with complex techniques being applied. There are numerous different techniques and combinations of techniques that can be applied. The assessment tool manages to address the key issues of LW while bypassing the highly technical aspects, allowing for its application across the spectrum of LW applications. A critique to this may be that some people would want to see

the technical aspects implemented. This endeavour would be highly exhaustive and the effort/gain ratio would be questionable. This is a possibility for further research if the ratio was analysed, but is out with the scope of this research.

The assessment tool was strategically developed to be holistic in nature whilst not being unnecessarily exhaustive. The layout is designed to be easy to follow, questions clearly asked and sections labelled. It is an effective self-assessment to determine the innovation readiness of businesses and research centres collaborating in LW. The questions are set in a yes/no manner deliberately to assess compliance with each factor and to avoid unrelated data being collected. The line of questioning is strategically developed to give insight to the RC regarding the knowledgebase and support they can tailor and offer approaching businesses. Simultaneously, it provides insight to these businesses on their own level of readiness to collaborate in LW.

The assessment tool directly addresses both a gap in knowledge and gap in practice. The data collected through the SLR and preliminary scoping interviews indicate this gap and was refined to develop this assessment tool to context. This avoids a blanket application of questioning, which some literature does. The assessment tool is modularised and adapts to the scenario at hand through user input. The input parameters are directly assessed to the output parameters based on the drivers that the business prioritises or selects. That is, if a business selects profitability as their driver for LW, then their focus and outputs are to be measured against profit margins. Similarly, if sustainability is their key driver, then sustainability-based parameters are what the outputs are to be considered against. The customer's use of the product and other drivers of LW, derived from the fourth pillar of LW, that is, intentions, is also another aspect emphasised in the assessment tool.

The level of readiness being determined by the RC may be a polarising point to the assessment tool. Every RC is unique and has their own contributing factors to their levels of readiness to collaborate, such as availability of resources and taking on new work, which varies through time. Perhaps the RC may have time to take on a project with a business that is knowledgeable due to limited scheduling. This research views an assessment from an approaching business as an enquiry, with details of their readiness and project boundaries. It can be considered as a strength to have the RC determine the readiness as opposed to the author as they are the collaborating partner. They can tailor their support

towards each readiness and contemplate further through conversations for certain enquiries. This is an interesting point for further research, where the comparison between the author determining the readiness vs. RCs determining the readiness, how it translates into practice and how the assessments differ between RCs. A key point of this research is not to have a definitive scale of readiness, but rather get the conversation going between collaborators and inform them of LW project boundaries and considerations. This is due to the practicality element of this assessment tool being used in industry. Realistically speaking, businesses are approaching RCs because they want to collaborate, not to meta-analyse the collaboration dynamics. While this is a research field of its own in academia and a very important one, this is supporting tool in industry.

7.3.2. Limitations

One of the potential critiques to the assessment tool is how an RC can compare answers with different collaborators due to the adaptive nature of it. This is not the intended approach with the assessment tool. While there are many points that can be compared and analysed if the RC wants to, each enquiry is unique and needs to be assessed individually by the RC to tailor their support to that context.

Another potential critique of this assessment tool is that it has too many questions that could be considered superficial, and the information gathered is limited due to the questionnaire styling of the assessment tool. While this may seem to hold some merit, the bulk of the questions require a yes/no answer. The point is not to exhaust the candidates with an over emphasis on details, but rather get to the point of “do you meet these criteria?” and identify the key aspects of LW and innovation readiness that stem from the literature reviews. Future research can develop on this assessment tool to find out more information from RCs on incorporate more qualitative input framed questions or to support the questionnaire with case studies. It can also develop the yes/no questioning layout to a Likert scale.

The research can potentially be critiqued to be heavily contextualised. This can be countered by saying that many frameworks in literature were generic, a compilation, or too comprehensive, with some researchers even pointing this out, some going on further to say that a lot of unnecessary data is being collected or unused (Enkel et al., 2011, Meina et al., 2018). By developing a modularised assessment

tool that is specific towards a specialised focus, that can be adapted to the business scenarios in the self-assessment is not common in literature and helps keep the research relevant.

A main limitation of this research is trusting that approaching businesses are filling in the assessment tool in an honest and accurate representation of their situation. For example, the procurement or marketing departments will answer it differently than senior management or the engineering department. Ultimately, this is a self-assessment which can guide an approaching business to being more ready, and they hinder themselves but inaccurately completing it or exaggerating. A guide can be placed to advise accuracy and that senior management fill it in, but the limitation does still exist that may only be discovered during further conversations.

Other methods of assessments or presentations were considered. The output could have perhaps used more detail, including spider diagrams, or graphs etc. The main point of this is not to analyse the answers extensively or visually present it, but rather assess if these points have been considered, if they have, that point adds to their readiness, if not, this is a point of improvement they can review. The assessment tool is geared more towards practice and aims to quickly assess enquiring businesses, so as not to dissuade them from completing the self-assessment, but provide the most information for them to consider their own readiness in the context.

As noted from literature is that RCs and businesses may have different goals in how to utilise the knowledge gained, with businesses leaning more towards confidentiality and RCs wanting to publish findings. This was addressed by asking if they are willing to negotiate with the RC to an agreed IP. It doesn't necessarily mean they will accept the IP proposals, but it shows the willingness of an approaching business and the position that an RC will take. A note of further research would be to have a detailed IP questioning centre, but that defeats the purpose of an initial indication. Another note for the business concerned of confidentiality in filling in the assessment is the RC can make a notice, whereby entering in information, it's automatically agreeing an NDA from the RC to not reveal information, and that by accepting collaboration, the NDA becomes superseded by the new IP agreement.

7.4. Final Conclusions and Contributions

This research initially endeavoured to find out the changes required for businesses to be innovative in the field of LW. Based on the author's personal experiences from being exposed to industry and data collected both from literature and industry, the research focus evolved to the innovation readiness between RCs and businesses collaborating in LW, a relevant and contemporary issue identified in practice. As discussed above, there is a dearth of research and information in this area, and this research met the objectives of the study within the limitation of the literature available. The outcome of this research was the construction of an adaptive assessment tool based on the boundaries that the context demands. The context boundaries were derived and formed from literature and contains the key applicable components identified in each research area.

The assessment tool was developed with the goal to get the conversation going between RCs and approaching businesses in LW collaborations, as well as be holistic, comprehensive and easy to use. With the various contexts this research contributes to, it would be of interest to several audiences, primarily the above-mentioned context, but also others in academia and industry. Firstly, for RCs that offer services in LW and those that don't. This assessment tool provides an initial step to collaborations and RCs can apply this assessment tool to LW or modify it to other fields of interest. Secondly, the assessment tool will be of interest to businesses that want to LW, whether or not that want to collaborate as it provides guidance on the key elements of LW and its applications. Finally, this research will be of interest to academia as it contributes to the innovation readiness in collaborations and LW research circles.

The American Education Research Association (2006), referenced in Randolph (2007) identified several ways in which research can contribute to knowledge, including

1. Contributing to an established line of theory and empirical research. This research contributed to the field of LW through the observation of indirect LW being conducted in industry. This research also contributed to the fields of LW and innovation readiness through the reviews of literature, identifying knowledge gaps and subsequent development of the assessment tool.

2. Motivated by a lack of information about a problem or concern. The management of LW is a narrow field with little information available on it, let alone the application of LW to the context of innovation readiness assessments between RCs and businesses collaborating together. This research explored several avenues to find information on the topic, including literature reviews, cross citations, SSIs and verification of the literature review processes with the Faculty Librarian.
3. Motivated by practical concerns. Because of this lack of information in literature, the research was defined primarily by a prevalent issue identified in industry through the exploratory SSIs. This fact advanced the contribution to knowledge and practice, a combination that the author believes is important to have.

To conclude, this proposed assessment tool is at its early stages, and would benefit from further work. It contributes to the field of LW management and the innovation readiness assessments of RC/businesses collaborating together. It seeks to support RCs in identifying the readiness of approaching businesses. It also seeks to support approaching businesses understand the key elements of LW and test if they are compliant to them or if they need further development to be more ready both in LW and to collaborate. This humble beginning is considered a positive step towards creating and raising awareness of the need for innovation management in LW due to the rapid global growth and practice of sustainability.

7.5. Future Research Directions

This field does hold many research opportunities. Below are some recommendations for other researchers.

1. Take this research further, apply the assessment tool to RCs that offer LW services and support this with the use of case studies on RCs and approaching businesses.
2. The context of this research raised an interesting line of thought of “Can the readiness of one collaborator influence the readiness of the other? If so, to what degree and with how many additional resources?” It is important to understand the varying levels of input an RC needs

to make to support varying levels of approaching business' readiness. This could help build the efficiencies of RCs and develop internal management.

3. Conduct a comprehensive study of indirect LW. LW is holistic and is embedded within the design and processes. Changes do occur frequently in industry and the ripple effect of these changes can be expected to have commonalities and differences. A further study into this could aid industry be more effective in managing these changes for traceability and repeatability.
4. Study the differences in expectations, capabilities and needs between approaching businesses and RCs. As there is a collaborative effort by both parties to innovate, it is can be seen to be necessary to understand the standings and expectations of each party to build a more realistic picture of what collaborative interactions would look like and a further understanding of the capacity to which the RCs can support businesses.
5. Compare between the researcher determining the readiness vs. RCs determining the readiness, how it translates into practice and how the assessments differ between RCs. A key point of this research is not to have a definitive scale of readiness.

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Appendices

Appendix 1 – Preliminary Scoping Interview Questions

Preliminary Scoping Semi-Structured Interview Questions

Innovation Management of Lightweighting Processes

Introduction to Research

- Project Overview – Aim, funder
- Confirm permission to record interview
- Sign consent form if not already done

Control Data (Participant information)

Participant job level	Role involves	Length of time in this role
□ Executive Board / Director □ Senior Managerial □ Managerial □ Senior Level □ Engineer □ Other	□ Driving & Monitoring LW and/or other innovative initiatives □ Participation creating innovative initiatives □ Lightweighting □ Collaborating with others □ None of the above □ Other	□ <1 year □ 1-5 years □ 5-10 years □ 10+ years

Primary Questions

1. Do you get any pressure to reduce weights of products? From who? And why?
    a. Are you working collaboratively with anyone (e.g. clients, suppliers) to achieve or promote lightweighting? What is involved?
2. How is innovation manifested in this company?
    a. Is it clear to staff?
    b. How are staff demonstrating it? Any examples?
    c. Are there any dedicated staff for lightweight/innovation activities?
3. Is there a strategy plan or process for lightweighting that you implement? Can you elaborate?
4. What are you finding difficult in Lightweighting?
    a. Are there any processes in place to stop this?
    b. What type of support would help you address these challenges?
    c. Do you find it difficult to achieve design integrity (Material/mechanical) in the lightweighting process?
    d. Do you find disadvantages to lightweighting?
    e. What would stop you from lightweighting?
5. Is there any lightweighting or innovating training for managers or staff?

Closing Questions

1. Is there anything else you would like to add?
2. Thank the participant

Secondary Questions

1. Do you set aside any time for lightweighting ideas generation? Who is involved in the meetings? How often are these meetings?
2. How do you monitor/measure lightweighting performance?
3. Are there any regulations that you are adhering to for lightweighting?
4. What do you think will be future challenges in lightweighting?
5. How aware are you of background systems (energy supply, materials supply, usage) in your analysis of a design?

Other possible questions to ask if the conversation leads there.

Lightweighting

1. Do you talk about lightweighting?
    a. Why?
    b. How do you go about it? (processes, tasks, etc.)
2. What drives the lightweighting initiative?
    a. Customers
    b. Regulatory Bodies
    c. Environmental Concerns
    d. Other (Please Specify)
3. Where are you focussing your attention?
    a. Design
    b. Materials
    c. Processing/Manufacturing?
    d. Other
4. What are the key differences of lightweighting in comparison to other methods?
5. Do you measure or monitor any of these key differences?
6. How is LW prioritized in day to day activities?
7. In your work, do you attribute anything specifically to lightweighting?

Challenges and Disadvantages

Differentiate between barriers, negative aspects.

8. How would you address lightweighting challenges?
    a. innovating with new technologies
    b. innovation processes
    c. manufacturing, (including multi material joining)
    d. optimisation
    e. material selection

Strategy and Vision

9. Do you know why a branch was opened up in Scotland?
10. Are there any company visions which are a direct response to lightweighting?

Innovation Culture

11. Is innovation measured/analysed within this company? (Innovation Capability/Maturity Frameworks)/ (number of identified problems in products and processes. Furthermore, have they been applied to LW?)
12. Is there any tolerance for innovation failures?

Competence and Knowledge (For new ideas and innovation projects)

13. How cross disciplined are your staff/colleagues with respect to design optimisation/manufacturing/materials?
14. In your designing of lightweighting, do you find any regulations need an update?
15. Do you find it difficult to fit in time for personal development and training?
16. Are there any knowledge transfer procedures in place? (Andrew S)
17. Is lightweighting perceived as an optimization task, a tool or a development target?
18. What tables of information do you use for lightweighting?
19. Are there any manufacturing methods implemented that are lightweight driven?

Organisational Structure

20. Is there any collaboration between any departments for lightweighting?
21. Cross functional teams with strong leaders?

Management

22. What does this company do in terms of development for lightweighting?
23. If a new conceptual design was shown to be more efficient through lightweighting, which ultimately would lead to fuel efficiency, would you consider it and if so, what would you do to consider it?

For OEMS

24. Do you monitor your suppliers and subcontractor’s carbon emissions?

Participant Information Sheet

Name of department: Design, Manufacturing and Engineering Management.
Title of the study: Innovation Management of Lightweighting Processes.

Introduction
My name is Adam Selim (adam.selim@strath.ac.uk). I am a PhD student in DMEM at the University of Strathclyde. You are invited to take part in a preliminary scoping interview of my PhD research. I am researching how companies are managing lightweighting processes.

Before you decide if you wish to take part, it is important for you to understand the context of the research and what will be involved. Please take your time to read the following information carefully. If there is anything which is not clear or you would like more information, please ask.

What is the purpose of this research?
This preliminary scoping forms part of my PhD research – 'Innovation Management of Lightweighting Processes'. The aim is to find out how companies are managing lightweighting. This includes but is not limited to perceptions of lightweighting, associated processes, challenges and other relevant discussions. This will help provide direction for the researcher.

This research is funded by the Advanced Forming Research Centre (AFRC), The University of Strathclyde and university faculty.

Do you have to take part?
No, participation is voluntary. If you decide to take part, you will be given a copy of this information sheet and asked to sign a consent form. Even if you decide to take part, you are still free to withdraw at any point without giving a reason and without any detrimental effect. If you decide to withdraw, your data will be deleted and not included in any analysis or publications.

What will you do in the project?
You will be participating in an interview answering questions relating to innovation and lightweighting. This is expected to take less than 1 hour.

You do not have to answer every question If you do not want to. Please feel free not to answer a question if you are uncomfortable with it.

Please note, do **NOT** provide any confidential information.

Why have you been invited to take part?
We are looking for participants who have relevant experience in managing lightweighting or are experienced in lightweighting.

What are the potential risks to you in taking part?
There are no significant risks foreseen in taking part in this study. If at any time you feel uncomfortable, please let me know right away. You are free to withdraw at any time and without explanation.

What information is being collected in the project?
The information being collected is current lightweighting and innovation issues that are being faced by companies, and how they are managing them.

At the start of the interview, you will be asked for your job title, job role and the length of time you have been in this role. This information will be analysed and corresponded with the information received from the interview.

As stated previously, please do not share any confidential information.

Who will have access to the information?
All information collected during the study will be strictly confidential and will only be available to people directly involved in the research project (i.e. the researchers and chief investigator).

The results of the preliminary scoping may be included within the researcher's thesis. However, all personal data will be anonymized.

Where will the information be stored and how long will it be kept for?
The information will be stored on a secure university computer, personal computer and backed up on the university server and cloud. Data will be stored such that it is only identifiable through an allocated participation code.

The audio recording will be stored on a secure mobile phone temporarily then backed up on a university computer, university server and cloud until they are transcribed. Afterwards, it will be deleted.

All data will be retained by the researcher until the completion of his PhD.

What happens next?
Results of the study may be published in the researcher's thesis, however any information about you will be anonymised (names removed) so that you cannot be identified from it.

Once you have read and understood the information above, and asked any questions if you are unsure, you may decide whether you wish to take part in this study.

If you are happy to continue, please sign the consent form provided. If you do not wish to take part in the study, thank you for your attention – you are free to leave.

Researcher contact details:

Adam Selim (adam.selim@strath.ac.uk)

University of Strathclyde, James Weir Building, 75 Montrose Street, Glasgow, G1 1XJ, United Kingdom

Dr Dorothy Evans (dorothy.evans@strath.ac.uk)

Advanced Forming Research Centre, University of Strathclyde, 85 Inchinnan Drive, Inchinnan, Renfrew PA4, 9LJ

Chief Investigator details:

Professor Jillian MacBryde (jillian.macbryde@strath.ac.uk)

University of Strathclyde, James Weir Building, 75 Montrose Street, Glasgow, G1 1XJ, United Kingdom

If you have any questions/concerns, during or after the research, or wish to contact an independent person to whom any questions may be directed or further information may be sought from, please contact:

Secretary to the University Ethics Committee
Research & Knowledge Exchange Services
University of Strathclyde
Graham Hills Building
50 George Street
Glasgow
G1 1QE

Telephone: 0141 548 3707
Email: ethics@strath.ac.uk

Consent Form

Name of department: Design, Manufacturing and Engineering Management
Title of the study: Innovation Management of Lightweighting Processes

- I confirm that I have read and understood the Participant Information Sheet for the above project and the researcher has answered any queries to my satisfaction.
- I confirm that I have read and understood the Privacy Notice for Participants in Research Projects and understand how my personal information will be used and what will happen to it (i.e. how it will be stored and for how long).
- I understand that my participation is voluntary and that I am free to withdraw from the project at any time, up to the point of completion, without having to give a reason and without any consequences.
- I understand that I can request the withdrawal from the study of some personal information and that whenever possible researchers will comply with my request. This includes the following personal data:
    - audio recordings of interviews that identify me;
    - my personal information from transcripts.
- I understand that anonymised data (i.e. data that do not identify me personally) cannot be withdrawn once they have been included in the study.
- I understand that any information recorded in the research will remain confidential and no information that identifies me will be made publicly available.
- I consent to being a participant in the project.
- I consent to being audio recorded as part of the project (Please select choice) □ Yes □ No

(PRINT NAME)	
Signature of Participant:	Date:

Appendix 3 – Findings from Preliminary Scoping Interviews

Candidate A

Management of Lightweighting

- The topics discussed were primarily technical aspects of lightweighting. The candidate seemed limited to discussing technical ways in which to lightweight, talking about lightweighting as a tool to use towards product innovation instead of discussing process innovation, i.e., choosing materials and design optimisation to achieve lightweighting as a goal. The company measures and presents lightweighting by "minimum weight vs. minimum cost", giving an option to clients to decide a method forward. While although this is a good visual representative of the two, this doesn't seem to be a strong methodology forward as these are two extremities, it would be helpful to have a standardised method to identify several costs vs. weights analyses to provide a range of options, presenting this in a graphical format. Though this may be difficult for companies that do not have an established process in place, or are in the initial stages of product innovation, with little resource.
- There was a comparison of designing for weight optimisation and designing for cost optimisation and giving the option between the two to customers and that parametric modelling helped this situation, such as min weight vs. min cost.
- The participant stressed that it was important to have a technical knowledge in order to lightweight and that training was an issue faced by people needing to lightweight. The candidate noted receiving high quality training was important.
- The candidate identified lightweighting as a scope, and that it is not different than design for manufacture. Various materials were the centre focus of lightweighting coupled with design optimisation earlier above. Manufacturing was perceived to be practically the same as standard manufacturing.
- There was discussion of the basic designing process that limited the cyclic design optimisation. The below process indicates a general engineering approach, not really providing unique aspects to lightweighting.

- Hand calculations – detailed designs – parametric modelling – validate through FEA and testing

Relevant Industry Issues and Potential Research Topics

- Companies driving lightweighting will face the challenge of achieving integrity. While design integrity is a given for well established companies and achieving it an obligation, the process to achieving it could be difficult for companies with fewer resources.
- Advice provided by the candidate was to look into advanced composites. This type of thinking seemingly provided a narrow viewpoint towards the understanding of lightweighting by the candidate.
- The candidate mentioned reducing reserve factors to 1 or reducing them to a minimum. It would be interesting to see if data is obtained to justify this reduction in reserve factor, or is a regulatory body providing this data for them, or perhaps they are just stipulating something.
- Technological developments can help improve time cycles.

Candidate B

This candidate presented a confident attitude, understanding and knowledge base in the details of lightweighting, it's application in industry and key relevant issues between research centres and industry. Below is a list of points noted from the interview.

Management of Lightweighting

- The candidate defines lightweighting as **"**Taking a genuine concept that has clear benefits through the concept again of being lighter in weight". The mission profile must include lightweighting, and the possible degree to which it is going to be achieved.
- Lightweighting is not simply just making things lighter, but identifying what is worth making lighter. That is, there must be a justification to lightweighting. Prior to its implementation, there is an assessment process of lightweighting suitability, considering the scope and priorities, in which the potential benefits are realised. Some questions pointed out by the candidate were "is

it a critical part? Does it need to be lighter? If so, why? How much will it cost to make it lighter? Is that going to offset its current cost?"

- It is a common fact that cost is associated with weight, and that to make something lighter, there is generally a financial benefit to it. The justification to lightweighting gives the designers an estimate to work with if they were to reduce the weight of something and defines the boundaries in order to still obtain a financial benefit from the process.
- It's a combined effort to help turn their idea into an innovative solution. Provide the steps needed to materialize the idea and help the client become innovative. In collaborative efforts, OEMs will tend to be clearer in their processes and specifications they are set in their ways and clear of their wants. Smaller companies have a great idea in their head, but to put it down is more difficult.
- The candidate's company works to bring to reality the idea that a company or person has, develop it further to enhance it if possible unless it's a build to print. They implement a standard manufacturing process and use informal, ad-hoc strategy plans and processes. The majority of clients are not aware of background systems, leading towards an awareness of carbon emissions, sustainability etc and the candidate tried to raise this awareness.

Relevant Industry Issues and Potential Research Topics

- Many clients misinterpret lightweighting to be associated with composites. Furthermore, to implement composites, new tooling, processes and everything downstream requires changing, which poses a risk to managerial staff, raising the mentality of "if it ain't broke, don't fix it".
- There should be more stopping factors to lightweighting other than cost, such as the ability to recycle and go back into the circular economy. Many composites end up in the landfill after usage.
- When asked about how they could receive help, the candidate stated that they got a lot of enquiries claiming to be lightweighting related but were not legitimately lightweighting, causing their performance parameters to be skewed and a lot of time wasted addressing these enquiries. The candidate indicated that there was a discrepancy between what clients understood lightweighting to be and what was actually lightweighting. The justification process is usually not carried out, companies just want it lighter, not understanding the process and implications. The candidate stated that if there was some sort of toolkit that could sift out and identify genuine

lightweighting enquiries from others, this would help them be more efficient with their time and prepare clients for collaboration with them.

Candidate C

The candidate was highly experienced in the aviation industry, an industry that utilizes lightweighting heavily, however, did not understand the term lightweighting. It was interesting that the candidate identified implementing lightweighting and an indirect method to lightweighting. Below is a list of points noted from the interview.

Management of Lightweighting

- At the initial stages of design, the ability to reduce weight is much easier than during manufacturing, as it is still within scope to amend it more. Any easy way to reduce weight will be implemented at this stage. This is an opportunity to make major changes as the product is still being defined since the supporting network has not been established. Since reducing the weight of an aircraft significantly reduces costs, with a knock-on cyclic effect of reduction pointed out that weight was the main driver initially, but cost took the focus later as they were looking into improving and streamlining processes. Once the design was complete, that is, to have the weights and balances established, it is harder for the primary focus to be reducing weight as this would alter the established design.
- Lightweighting is intertwined with other aspects throughout manufacturing, by designing with weight as a priority in the initial stages, it can possibly lead towards combined components, reducing joints, reducing assembly time and cost at the later stages during manufacturing.
- For a development project, they are focused on rate, cost and weight. That is, how quickly can they build them? What is the cost of building them? And can we reduce the weight?
- At the initial and design stages, aircraft performance is a higher priority than cost to manufacture. Subsequently lightweighting is a significant driver. They lightweight by using lighter materials, reducing the number of joints through redesign, applying a new manufacturing technique such as

resin transfer moulding and by being smart. The candidate identified being smart by challenging the given requirements. Make the client decide whether it is really important to have something designed with strict adherence to requirements of have something cheaper. It is important to mention to clients the cost savings with some of the requirements slightly relaxed, and sometimes with performance affected. It is noted that design integrity is a given in this situation and fit for purpose.

- Weight Neutrality: Reduce cost and maintain the same weight. While, it does not immediately seem to be lightweighting, this is identified as a form of it as the reduction of cost is likely to increase the weight, and they are applying similar lightweighting techniques to keeping the weight the same. If there are any bottlenecks through the production line, engineering is consulted to identify how to redesign a part to reduce time in manufacturing. This this is an important feedback loop in reducing cost and maintaining the same weight.
- There has to be justification to use a new method since its implementation can possibly require a redevelopment or replacement of infrastructure. This justification must meet a company's driving initiatives and/or provide financial gain, market security, sustainability, etc. While risk is a factor in this, giving the managers that "warm fuzzy feeling" through quantifying as much as possible the risks involved and manage them.
- Customer's requirements are the main driver and they work from there to decide suitable engineering methods and materials forward in the engineering side of things.
- Everything has to be at a certain level of quality, but the effort and cost to achieve is subject to review. If something is costing more than what is expected, they will consider proposing new ideas to clients by challenging the requirements to reduce costs.
- Relevant staff are trained to minimize as part of the basic training.
- They have a cross departmental team which speaks with required departments to get a new piece of technology integrated to the aircraft.
- After the design is established, the focus becomes streamlining processes.

Relevant Industry Issues and Potential Research Topics

- Similar to candidates A and B, there is often pressure to reduce weight by clients. They still offer the client a lower weight and lower cost options and give them the option, but there is a focus into reducing timescales in production as this can save cost and help delivery schedules. The ultimate end is cost, and perhaps amongst other things, winning a contract.
- They will try to get suppliers to do more assembly work for them than to make it in house. It is generally more expensive for them to make something than for suppliers to do it.
- Innovation is manifested in the R&D department, Technology readiness levels are considered, with cost and engineering requirements as constraints. Engineering and other departments are consulted for the possible applications. There is a balancing act between cost, engineering requirements and new technologies.
- There is such a big drive on cost and time that the scope of implementing weight neutral pieces of technology onto the overall product requires a heavily orchestrated multi-departmental effort.

Candidate D

Management of Lightweighting

- Weight is always thought of within aerospace and is in the periphery of everything done. Its review can have trade-offs and many companies associate cost to a kg of weight. They had a document which pointed out savings per kg.
- You have to consider the knock-on effect that one change would have further downstream. Making something lighter might initially seem beneficial, but there has to be the decision-making process to see the global benefit since there are many variables that are linked into changing one process.
- The candidate views lightweighting in terms of the benefits they can get from making lighter parts.
- If at a point there is the possibility to improve a process, weight is a considered factor.
- The candidate identified lightweighting as making lighter parts through using alternative manufacturing methods, gaining benefits from doing so, improved material properties and integrating multiple components into a single component such as removing joints.

- There are long term goals set out by the company to achieve a certain weight, carbon emissions, etc. These goals help provide the vision that the company is trying to achieve.
- During the initial stages of design, weight reduction is a major part considered due to aircraft performance. However, once something is in service, there is the questioning process of why things are the way they are. Individual components are considered alongside adjacent components, the manufacturing setup, and other tied in factors.

Relevant Industry Issues and Potential Research Topics

- They are looking at removing joints and trying to design something to be an integrated single component rather that several. in that finding a new way to combine different components, this helped reduce joints, which in turn lead to a lighter weight, but the surrounding infrastructure needs to support this change. The alternative manufacturing methods are compared against the original manufacturing methods and weight is heavily considered within this decision-making process.
- Because designs have already been established and many lightweighting exercises have been implemented previously, the degree of lightweighting required now raises the question “is it worth it?” Perhaps for some companies, particularly new start-ups, it can be more useful to lightweight than more established companies that have implemented many lightweighting exercises.
- A challenge to lightweighting in the candidate’s work environment is that conventional manufacturing methods are tried, tested and used for many decades. The alternative must have a strong case to be taken forward.
- Difficulties in lightweighting include manufacturing methods, lighter materials with suitable properties are generally more expensive and perceived as the main way to lightweight. Furthermore, geometrical constraints and the knock-on effect may hinder a weight reduction process.