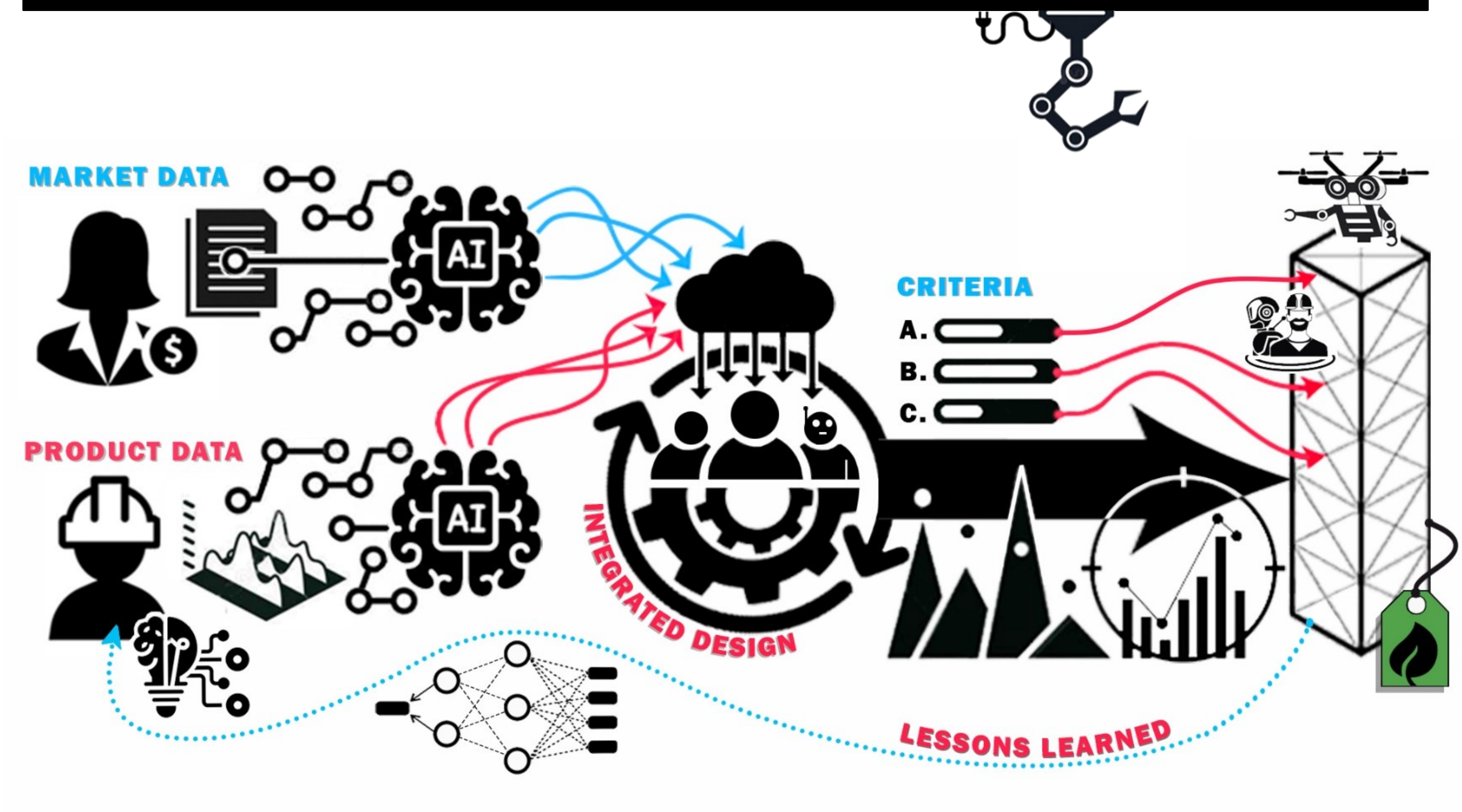

Data-informed Building Procurement:

A contractor exploration on embodied-carbon targets through Buildability and AI

Master's thesis in Design and Construction Project Management

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CHALMERS UNIVERSITY OF TECHNOLOGY
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MASTER’S THESIS ACEX30

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A study at NCC Building Sweden
Master’s thesis in Design and Construction Project Management

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ABSTRACT

The construction industry has been object of criticism due to poor productivity rates, lethargic development, and irresponsible use of natural resources. It has been pointed out that segment peculiarities, such as fragmentated, project-based, and one-of-a-kind, stand as barriers for change, compromising the urgent agenda for sustainable development. Regardless of that, recent climate agreements have input unprecedent pressure on the industry with challenging decarbonization goals. Motivated by that, this thesis explores a Swedish contractor perspective on how embodied carbon targets can be addressed in the building sector through better-informed tender briefings and buildability. For that, the study follows an abductive reasoning and exploratory mixed method approach, where a broad qualitative study informs a quantitative survey.

Findings reveal a clear need for better-informed decisions on tender briefings. It exposes that data in early stages is reduced and inaccurate due to undefinitions and undeveloped assessments methods that tackles limited criteria. Additionally, it is argued that information flows are difficulted by outdated practices and the fragmented reality of conventional buildings product development, in which several stakeholders co-create, negotiate, and transfer asset ownership along the way. These actors, as investigations support, usually hold opposing interests driven by short-term economic gains. Consequently, neither environmental nor societal criteria appear to be effectively informed and spoken for during early stages of decision-making, regardless the considerably high share of emissions and relevant social issues that the sector comprise. Further, it is exposed that decarbonization roadmaps proposing investments in greener materials solutions, although longed-for, might escalate building costs considerably, possibly leading to economic and social issues linked to housing prices. Therefore, it is argued the plan may turn unfeasible, especially in face of the broad implementation which is vital to attend set targets.

Accordingly, seeking to compensate such economic impacts, the thesis explores opportunities to reduce waste through the promotion of Buildability principles in the earliest stages of concept design, when it can still be addressed. As such, obstacles and inflexibilities created via client requirements and tender procedures are analyzed to propose changes.

However, findings show *the public procurement act* challenges contractors ability to influence on more *buildable* solutions in public tenders. And *Partnering* strategies, which are often seen as a remedy for that, has been reducing due to public clients fear of volatile budgets - a viewpoint which contractors oppose since *Partnering* is a mean for many ends. Consequently, the thesis concludes that contractors are dependent on client's leading role and can hardly count with better informed briefings and *easier to build* requirements.

Nonetheless, it is suggested that contractors could develop a strategy based on data-informed '*side-offers*', as a way around the limitations framed by the public procurement dynamics. Accordingly, a roadmap for AI-applications is advocated for contractors to reduce lead-time and resources spent for the elaboration of these *side-offers*. For that, it recommends the use of cutting-edge technologies to process an integrated multi-criteria design, that is informed by data collected both from the product and the market (client). Ultimately, the thesis supports that through automation, contractors can gain access to the right information at the right time, and thus promote a more valuable and sustainable alternative for public clients to procure.

Keywords: sustainability, buildability, public building procurement, client requirements, tender briefing, early contractor involvement, integrated design, decarbonization, information-flow, value, AI.

SAMMANFATTNING

Byggindustrin har varit kritiserad för låg produktivitet, långsam utveckling och hänsynslös användning av resurser. Det har visat sig att vissa särdrag som kännetecknar barriärer mot förändring såsom *fragmenterad* och *projektbaserad* har förhindrat den hållbara utvecklingen. De senaste klimatavtalen med utmanande mål för koldioxidminskning har ansträngt industrin. Med detta som grund har denna studiens syfte utvecklats till att undersöka hur målen om inbäddad koldioxid kan länkas till byggindustrin genom en bättre informerad anbudsprocess, förfrågningsunderlag och byggbarhet. Därför har denna studie utvecklats med abduktion och blandad forskningsmetod där en omfattande kvalitativ studie ligger till grund för en kvantitativ undersökning.

Resultatet visar att informationen i tidiga skeden är begränsad och kan bli felaktig pga. outvecklade bedömningsmetoder med otillräckliga kriterier vilket i sin tur leder till ett större behov av ett välinformerat förfrågningsunderlag. En följd utav omoderna metoder och den fragmenterade verkligheten av den konventionella produktutvecklingen av byggnader, resulterar i komplicerade informationsflöden där intressenter förhandlar och överlåter ägarskap. Dessa aktörer har ofta motstridiga intressen pga. kortsiktiga vinster och därför är varken miljömässiga eller sociala svårigheter effektivt kommunicerade i tidiga skeden. Vidare visar resultatet att vägledningar för koldioxidminskning föreslår investering i miljövänliga lösningar, vilket i sin tur kan öka byggnadens kostnad samt leda till ekonomiska och sociala konflikter. Därför ses denna lösning som utmanande och näst intill omöjlig att genomföra pga. den implementeringen som krävs för att uppnå uppsatta mål. För att uppmana industrin till att kompensera den ekonomiska påverkan analyserades förfrågningsunderlag och beställarkrav med detta som grund. Här har LOU begränsat samarbetet i tidiga skeden mellan beställare och entreprenör.

Denna studies slutsats har grundats i hur beställarens roll har påverkat entreprenören och begränsat byggbarheten och utvecklingen utav data-informerat underlag. Således har vägledning för AI-verktygen uppmuntrats i syfte att underlätta för entreprenören i mån av tid och resurser. Flera kriterier med data-informerat designkoncept kan möjliggöra sidoanbud. Genom att automatisera anbudsskedet kan entreprenören få tillgång till rätt information vid rätt tid och skapa mer värdefulla och hållbara lösningar för offentliga beställare.

Nyckelord: hållbarhet, byggbarhet, offentlig upphandling, beställarkrav, förfrågningsunderlag, tidig entreprenörsmedverkan, integrerad projektering, koldioxidminskning, informationsflöde, värde, AI.

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PREFACE

This report presents the master's thesis for the degree in Design and Construction Management (DCPM), conducted at the Department of Construction Management and Structural Engineering at Chalmers University of Technology. Along one semester, the authors explored how resource-efficiency, and in turn embodied-carbon targets, could be addressed through the promotion of Buildability in tendering processes, in perspective of a large Swedish building contractor. We have come to diverse insights and conclusions that are shared in this paper. Also, throughout this process, the intensive discovery and learning journey served as a transformational process for the authors. Accordingly, we hope readers find it as interesting to read, as it was for us to produce this study.

The knowledge acquired along this 2-year programme - more particularly during the construction of this last assignment - comes to consolidate and further reinforce the authors passion and curiosity to explore innovative ways to do business in the building sector. Being part of the change for a more sustainable future turns, hence, more than ever into a strong personal drive to be further perceived.

However, this process would have not been made possible if it were not for the availability and support provided by the two inspiring supervisors - Linda Cusumano and Rasmus Rempling. It is only fair to recognize their roles exceeded the ordinary supervision, as their eventual mentoring's were vital for the upkeep of authors motivation and morale along the way. We are extremely thankful for that privilege.

Other relevant people and organizations we are profoundly grateful for:

- Our families and friends, who supported us along the way.
- On Ricardo's side, a special huge thanks to my spouse Elin, and both my children Lennon and Louie, for recharging my energy and being greatly supportive
- 'NCC Building', as the hosting company
- SBUF, for backing the research
- Urban Werner ('Werner Consult'), for the long, open, and insightful talk, as well as the help with contacts provided for the interviews and survey
- All interviewees and survey respondents

Last but not least, thanks to ourselves for all the hard work put into this.

THANK YOU!

Ricardo Alencar
Viktorija Jovanova

Gothenburg, June 2021

Acronyms

AMA AF Administrativa Föreskrifter (Administrative Regulations) 21, 37, 44, 59, 61

BBR Boverket's Building Regulations 15, 19, 22

BOQ Bills Of Quantities 28, 36, 37

CCS Carbon Capture Storage 11, 46

DB Design-Build. 3, 7, 18, 20, 22, 23, 31, 41, 43, 51, 52, 53, 54, 55, 56

DBB Design-Bid-Build 20, 22, 23

EIC Early Involvement of Contractor 3, 18, 23, 28, 37, 43, 56, 57, 58, 60

EKS European Construction Standards (Europeiska Konstruktionsstandarder) 20

EPD Environmental Product Declaration 9, 14

ISO International Organization of Standardization 21

LCA Life Cycle Assessment 9, 10, 12, 16, 31, 37, 38, 41, 44, 45, 48, 54

LCC Life Cycle Costing 13

LOU Public Procurement Act (Lagen om Offentlig Upphandling, LOU) 20, 28, 37, 43, 60

MCDA Multi Criteria Decision Analysis 9, 12, 38, 41, 48, 54

MMC Modern Methods of Construction 36, 55, 58

PBL Planning and Building Act (Plan- och Bygglagen) 20

PBF Planning and Building Ordinances (Plan- och Byggförordningen) 20

PCR Product Category Rules 12

SCM Supply Chain Management 51, 53

TBL Triple Bottom Line 9

1 Introduction

An introduction to the thesis is presented in this chapter. The background in which the study takes place is presented, followed by the purpose of the thesis, the research question's structure, and lastly the scope.

1.1 Background

The construction industry is one of the main drivers of the global economy due to its high contribution to the developed and developing countries' GDP (Rempling et al., 2019). In Sweden, the share of investments in construction in 2019 was 10.7% of the GDP, representing almost a 2% rise since 2009 (Byggföretagen, 2021), and Boverket further estimated in 2019 that, until 2025, Sweden would need 600,000 new dwellings (Boverket, 2018). However, an expanding construction industry results in an increasing environmental impact. The use of natural resources in construction affects the ecosystems largely; therefore, this impact represents a challenge for the industry (Rempling et al., 2019).

To meet the challenges of minimizing environmental impact, Fosilfritt Sverige (2018) emphasizes the importance of setting long-term goals and collaboration between actors. It is also suggested that all actors should increase their knowledge regarding responsibilities and drive the development forward by taking initiative through calculating climate impact, digitalizing different processes, reporting their sustainability actions, and setting goals internally. This, as argued by Goubran (2019), implies in organizations change.

However, it has been revealed that the highest carbon emissions related to construction derive from the manufacturing of building materials (Fossilfritt Sverige, 2018). Consequently, although a change in organizations' approach to reducing waste and accomplishing resource efficiency is imperative, materials manufacturing procedures need to be advanced to sufficiently reduce the sector's impact (Karlsson et al., 2020). It has, thus, been advocated in recent industry roadmaps to promote electrification, biofuels, carbon capture techniques, and other eco-friendlier production practices to mitigate and possibly neutralize carbon impact until 2045 (ibid). Although promising, however, such techniques may well lead to alarming rises in construction costs and housing prices. After all, as the saying goes, "*there is no such a thing as a free lunch*" (Friedman, 1975). Therefore, it is often wise to wonder, *who will be paying that bill*?

Following that logic, if not enough investments are made available to fund these changes, the whole strategy may turn economically unfeasible and thus unsustainable, especially in the required speed to meet such targets. Thus far, yet that seems to be the only thinkable way to reduce carbon impact considerably, and so it is reasonable to believe that the 'economic' dimension of Sustainability will play a central role in reaching these goals. The need for cost savings by optimizing construction processes is therefore, more than ever a pressing agenda to possibly compensate for the upcoming investments in pricier materials manufacturing.

Still, as of authors' best knowledge, until now this issue has been overlooked by most actors in the industry and academia. Likewise, most research approach construction sustainability exploring the impacts of its activities on social, environmental, and economic dimensions from a broad perspective (Rempling et al., 2019). Hence, there is a perceived opportunity to investigate the practical and bureaucratic matters in-depth (such as regulations, client requirements, and tendering dynamics), that naturally contextualize and frame how construction is undertaken in the building sector.

This knowledge gap is, to the authors' best knowledge, untraveled ground and calls for attention.

1.2 Aim

This thesis aims to explore ways to promote a more resource-efficient construction process, possibly by supporting easier-to-build solutions (Buildability) via better-informed building procurement. The study focuses on the complexities of the tendering phase, especially on Client requirements and pre-contractual inter-relations between Clients and Contractors. Ultimately, as research in collaboration with a large Swedish construction company, this thesis aims to emphasize the perceived opportunities for Contractors to assume responsibility for change in pursuit of a more efficient, and thus sustainable building sector.

1.2.1 Objectives

1) Identify the current status and challenge(s) for embodied carbon neutrality to be reached until 2045, as set in Sweden by the climate act.
2) Review the potential of Buildability principles to improve resource-efficiency, and as a result, possibly develop the economic and environmental aspects of Sustainability in the building sector.
3) Identify through interviews, survey, and tender documents analysis, the types of client requirements that most frequently challenge Buildability.
4) Investigate through interviews, survey, and tender documents analysis, how contractors are framed by regulations, clients, and business dynamics, to make use of their expertise on early design phases.
5) Evaluate if contractors can influence change in tenders to encourage more resource-efficient solutions.
6) Assess the potential of AI solutions to support better-informed building procurement.

1.2.2 Research Questions

To address the research goals, four research questions are envisioned inspired on the principle of *the golden circle* (Sinek, S., 2009). In that, organizations are suggested to start with the purpose - or **why -** they do what they do. Followed by that, it focusses on **how** to achieve such purpose through processes. And last but not least, it is supported to define **what** product or service can be delivered to achieve that goal.

Appropriately, in this thesis the RQ1 addresses the main purpose, or '***why***' there is a pressing need for change. Subsequently, '***how***' that change could be achieved, is tackled through RQ2 and RQ3. Finally, RQ4 reveals '***what***' practical solutions could possibly help providing the envisioned purpose.

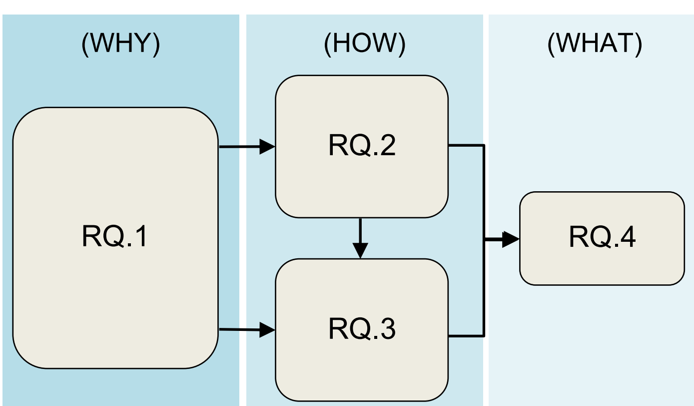


Figure 1.1: RQs sequential reasoning

Following that structure, the following research questions are defined.

RQ1: In a changing building sector, how is the contractor's responsibility framed by the climate agenda, business dynamics and traditional tendering practices?

RQ2: Is there a link between Sustainability and Buildability that can serve as a driver for change?

RQ3: How can contractors promote resource-efficiency in the building sector?

RQ4: What kind of AI-based tools could aid contractors in their strive for Buildability and, in turn, potentially promote more sustainable practices?

1.3 Scope

This thesis focuses on the early stages of construction projects, more specifically on the tendering processes in Design-and-Build (DB) contracts for public building projects and the possibilities of Early Involvement of Contractors (EIC). No specific project case was studied in depth. However, an analysis of several tender documents takes part in the holistic investigation chosen to obtain an overall view of the Swedish construction industry, particularly the product development stage.

As part of the Theoretical Framework, the literature review considers international scientific papers and reports from different organizations, including Swedish, focusing on the themes of Buildability and Sustainability, but also Procurement regulations, standard agreements and other laws related to these topics. It also briefly introduces some cutting-edge technologies identified during the studies to be potential solutions for the studied organization to adopt.

Furthermore, the interviews - part of the empirical study - are aimed at business managers from the largest construction companies in Sweden and reached 15 interviewees, of which approximately three per company. The survey contacted by email more than a hundred Contractors' representatives, but due to time constraints, only twenty-nine respondents answered the instrument. Thus, generalized conclusions on that collected data are somewhat limited.

2 Research Methodology

This chapter provides a detailed explanation and justification of the research approach and the chosen research methods for this thesis. Furthermore, stepwise described how the mixed methods are used to answer the research questions and the purpose of the study as a whole.

2.1 Research Approach

According to Creswell and Creswell (2018), research approaches are plans and procedures for research that span the steps from broad assumptions to detailed data collection methods, analysis, and interpretation. The data collection method affects the analysis of data (Fellows and Liu, 2015). A proper approach selection should be guided by the nature of the issue being addressed, the researchers' personal experiences, and the audience (Creswell and Creswell, 2018). As such, the following approaches are addressed in this research, and the reasoning is further explained ahead:

a) *Qualitative research* ascribes to a social or human problem. It involves emerging questions and procedures and the researcher making interpretations of the meaning of the data. Flexible.

b) *Quantitative research* tests objective theories examining relationships among variables, which can be measured (i.e., by instruments) and analyzed using statistical procedures. Structured.

c) *Mixed methods research's* core assumption is that the integration of qualitative and quantitative data yields additional insight beyond the provided by each approach alone. Creswell and Plano Clark (2007) identify four mixed methods designs, and the exploratory sequential is perceived as the best fit for this thesis goals.

2.1.1 Research Reasoning Design

The exploratory research design is illustrated in Figure 2.1.

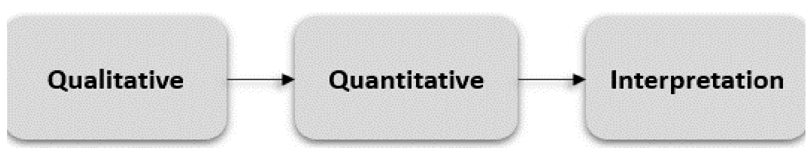


Figure 2.1: exploratory sequential approach. Inspired on Saunders et al. (2019)

As tackled by Creswell and Creswell (2018), in an exploratory sequential approach, the researcher begins with a qualitative phase to explore views and inform a subsequently quantitative phase. It is particularly helpful in relatively unstudied areas (Borrego et al., 2009), especially since, as argued by Merriam (1988), the author's view of subjects affects the complete research process. As such, one needs to build awareness to ask *the right* informed questions.

Accordingly, since this study aims to shed light on a complex, broad and sub-explored topic - in which the authors have limited previous experience with - the research approach follows the *exploratory* sequential design. Moreover, as such, it is strategically divided into the following parts:

p.1) Qualitative (exploratory); p.2) Quantitative (meta-data collection); and p.3) Analysis:

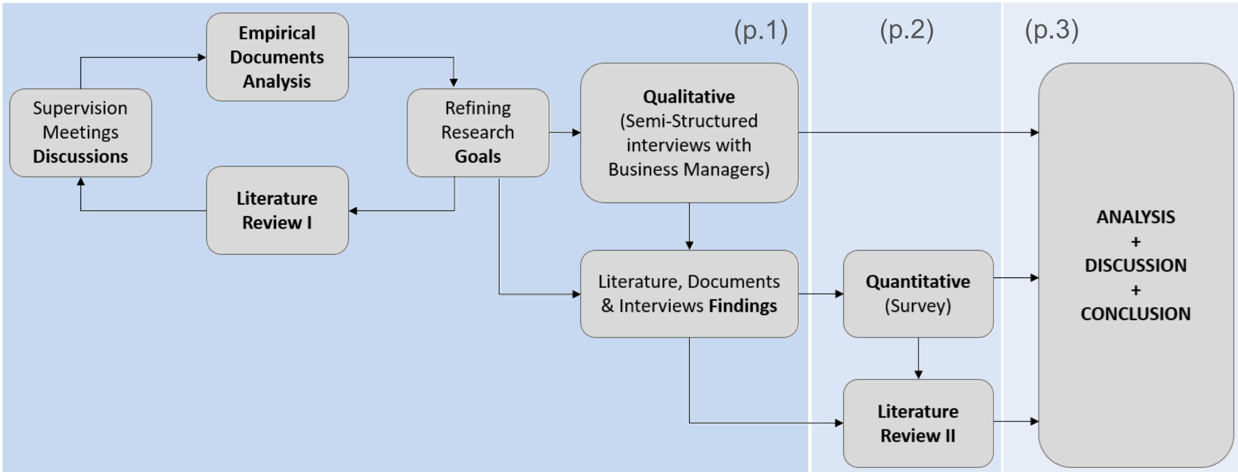


Figure 2.2: Research design, conceived by the authors, inspired by Wright et al. (2015)

p.1) As shown in *Figure 2.2* above, the qualitative part starts with intensive supervised discussions, analysis of tender documents, and readings on diverse related literature (papers from the Industry and Academia, news, regulations, etc.). That process is quite iterative and can be characterized as 'abductive', since new insights open new research paths to be explored, leading to more findings. Moreover, although that procedure extends the study to a surprisingly broad scope at first, it also helps the authors explore views (Creswell's) and construct their perspective of the whole picture. As awareness is built through that learning journey, 'dots' start to get linked, and more specific assumptions emerge, leading to a clearer scope with refined goals. Such process is supported by (Alvehus, 2018) argument that the 'exploratory' approach fits for 'abductive' reasoning since the goal is to find accepted assumptions to be further questioned through a second quantitative step.

Still, in the first part (p.1*)*, as insights arise from readings and supervised discussions, the research goals are defined, and semi-structured interview questions are conceived. Such interviews are conducted with senior business managers experienced in tendering (more than ten years). The collected qualitative data from these interviews provide findings but also more in-depth questions that are better tackled through a qualitative instrument.

p.2) Such new questions, together with a few inconclusive answers from the interviews (perceived as too open or divergent opinions), are tackled in the second (quantitative) part, using a survey to confirm emerged assumptions as supported by Creswell and Creswell (2018). Allowing, hence, for the collection of accountable data that can be further analyzed. Along with that, more literature is reviewed as required.

p.3) Data collected from both qualitative and quantitative instruments are examined, and the findings are compared with the reviewed literature in an *analysis* chapter. Following that, a critical interpretation of such analysis is approached in a *discussion* chapter, providing answers to the four predefined 'Research Questions'. Ultimately, a *conclusion* chapter presents the authors' suggestions, end remarks, and reflections on what has been delivered in this thesis, and possibilities for future studies.

2.2 Literature review

The literature review is based on scientific papers. It is used to describe the theory behind the topic and, along with initial empirical research, set the basis for constructing the interview questions. According to (Snyder, 2019), the process of conducting a literature review includes four different phases: designing the review, conducting the review, analyzing, and writing the review. Following this idea, the first step aims to decide if there is a need for a literature review within the studied subject (Snyder, 2019). Such a need was discovered when the goals and research approach of this thesis were defined. The second step is to search for relevant scientific papers to conduct the review. For that matter, different databases are used, such as Chalmers Library, Scopus, Science Direct, and Google Scholar. Keywords used in this process are buildability, triple bottom line, building procurement routes, client requirements, and early contractor involvement. A second round of Literature review is perceived as necessary after the data collected from the different sources are analyzed and interpreted. Keywords used in the second review are Swedish building procurement regulations, prescriptive and performance requirements, generative design, character recognition, floor plan recognition, text classification, convolutional neural networks.

2.3 Empirical Research

Empirical data is sequentially collected using three different approaches, as follows:

1. Tender documents analysis: Investigations on past cases' requirements
2. Interviews (qualitative): Semi-structured and exploratory
3. Survey (quantitative): Assessment of in-depth practical issues
4. Studied Organization overview: A brief view on the company's values and sustainable culture

2.3.1 Tender Documents Analysis

To better understand the problem statement related to building projects' tendering processes, the studied organization (a leading Swedish contractor) provided several tender documents from 12 recent building contracts (from 2019 and 2020). Such documents were previously conceived by project owners, commonly known in the construction industry as 'clients' (or developers), and contain information describing what service needs to be executed and in what conditions (Bröchner and Kadefors, 2009; Mofti and Mofti, 2015). After conceived, these documents are handed out to best-fit contractors (builders). They will then study the material, evaluate competitive alternatives, and make calculations to provide proposals aiming to win the competition for the project execution. The number of documents provided by the client in each tender and assessed in this study are shown in Table 2.1. Drawing files are not counted or analyzed due to time constraints.

Tender name	Docs. provided	Tender name	Docs. provided
Tender 1	9	Tender 7	7
Tender 2	8	Tender 8	19
Tender 3	2	Tender 9	15
Tender 4	13	Tender 10	11
Tender 5	23	Tender 11	40
Tender 6	20	Tender 12	19

Table 2.1: Number of documents analyzed in each tender project

2.3.2 Interviews (qualitative approach)

To explore the subject of this research, the profile of the interviewees aimed at senior business managers, with strong relationships with clients and tenders and a background in production. The choice for that profile was grounded on the need for a more holistic awareness of the whole cycle, with a strategic view. After conducting some interviews with business managers, a need for insights from other perspectives than business managers were perceived. However, due to the limited time, only one consultant and one design manager were communicated through a semi-structured and open interview (interviewees 13 and 14).

Accordingly, the following interviewees took part of this exploratory phase (Table 2.2).

	Name	Company	Role	Region
1	Karin Forsvall	NCC	Business manager	Skåne
2	Robert Karlsson	NCC	Business manager	Halland
3	Peter Höög	NCC	Business manager	Örebro
4	Emil Junelind	NCC	Business manager	Stockholm
5	Mats Bergendahl	NCC	Business manager	Stockholm
6	Robert Malmgren	Peab	Business manager	Skövde
7	Andreas D'arienzo	Peab	Business manager	Gothenburg
8	Patrik Hjelte	Serneke	Business manager	Gothenburg
9	Emil Lind	Serneke	Business manager	Gothenburg
10	Christoffer Kennedy	Skanska	Business manager	Gothenburg
11	Jonas Celadar	Skanska*	Business manager	Gothenburg
12	Mikael Matts	Skanska*	Vice-president	Sweden
13	Urban Werner	Werner Konsult	Consultant	Gothenburg
14	Anna Joelsson	NCC	Design Manager	Skåne
* recently changed roles/organizations, but answered interviews based on knowledge from that.				

Table 2.2: List of interviewees that attended the qualitative research

2.3.3 Survey (quantitative approach)

The survey has been attended by business and project managers, as well as bidding specialists working for one of the leading contractors in Sweden and experienced with public building tenders. In relation to the interviews, it can be noted a change both in terms of sample - expanded to consider more experts - as well as a further in-depth focus on regular DB public tendering. That decision is taken due to the perception that such a procurement route is very popular and presents interesting opportunities for improvement. Other than that, the profile of respondents is extended due to more in-depth questions and a necessity for the population.

105 contractor's representatives were emailed via a survey webpage, and 29 completed the questionnaire, resulting in a 27.6% return rate. Of these, 51.72% are business managers; 10.34% are project managers; 17.24% are bidding specialists; and 20.69% other positions, such as 'regional managers', 'bid calculators', and 'technical specialist'. The respondents are based in diverse Swedish regions.

2.4 Quality Analysis of the Research Method

The mixed-method sequential exploratory approach has worked quite well and proved to be the right choice for this thesis. As the theory supports, the first qualitative step offered a holistic awareness of the topic and related subjects. However, since it was not so clear where the research was going, a very wide investigation was conducted during that time to discover a relevant central argument to develop upon. Although quite consuming, the authors had a very rich learning journey that surely served as a transformational process. On the other hand, some specific decisions could have been made differently. To mention a few, the semi-structured interviews were conducted with senior business managers aiming to achieve a more holistic understanding of the contractors' business. The idea was to approach at the same time the tendering dynamics, as well as internal bidding procedures and the potential of knowledge transfer from production. However, that choice also revealed some obstacles. First, such senior individuals were quite hard to reach, and a lot of time was invested in contacting them. Second, their insights, although interesting (particularly regarding the strategic tendering dynamics), also were many times perceived as too open and vague. It felt that most of them either avoided compromising or lacked the in-depth knowledge from operational tasks. Therefore, contacting operational professionals that are more involved with the hands-on tasks (such as bidding specialists) could have also been valuable to reveal the more practical difficulties.

Also, it could have been interesting to interview managers on the client's and consultant's role, since they could give their side of the story (instead of taking all the blame). Questions could be why they use special requirements on top of standard agreements, why partnering is reducing, why don't they early involve the contractors more often to conceive tender briefings, why they detail more with consultants instead of involving contractors to do that, why don't they use more performance requirements instead of technical ones (which specify 'how' to build), how they think that sustainability could be improved in the process (tenders that prioritize long-term value instead of short-term gains), and many others.

2.5 Ethics

The empirical part of this thesis consists of tender documents analysis, an interview study, and a survey. To avoid any ethical issues, all tender projects analyzed are kept unnamed, labeled by numbers. The interviewees were well informed of the purpose of the thesis and of how their answers and names are used. Their names are presented in a list but not linked to quotes. It was of great importance for the authors to record the interviews in order to be consistent with the writing of the thesis. Furthermore, all interviewees were asked permission to record. The interviews were semi-structured for the interviewees to participate in the discussions without the authors affecting their answers. Lastly, the survey is anonymous.

3 Literature Review

The theoretical part of this thesis is presented in this chapter. The first section explores the sustainability subject, followed by buildability, buildings procurement, and lastly technologies.

3.1 Sustainability

The subject is primary approached by holistically presenting the sustainability concept. The study then narrows the investigation down to more in-depth subjects, such as the current status of buildings CO_2 emissions (A1-A5) in Sweden and the recently proposed decarbonization roadmaps. Following that, a brief report of environmental evaluations and related tools such as LCA, EPD, and MCDA, is presented.

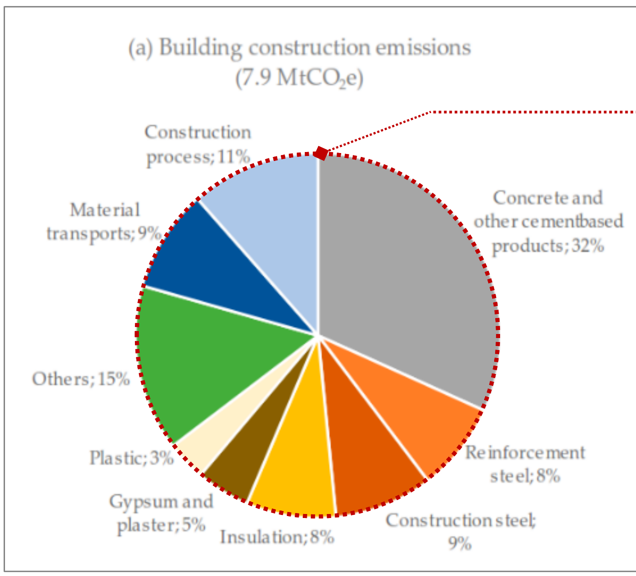
3.1.1 Triple bottom line

Sustainability and sustainable development are widely known terms, often related to the challenge of reducing environmental impact, pollution, emissions, and climate change (Hedenus et al., 2018). The term "Sustainable development" dates back to 1987, when introduced by the "Our common future" report (World Commission on Environment and Development, 1987), and implies that humanity must ensure that the needs of the present generations should not compromise the ability of future generations to meet their own. Most of the definitions of *sustainability* emphasize the importance of balancing environmental, economic, and social factors, often referred to as the three "pillars of sustainability", "dimensions", "components", "aspects", etc. (Purvis et al., 2019).

Organizations and businesses are mostly driven by growing production rates and short-term earnings (Brønn and Brønn, 2018). Consequently, the balance of the three pillars often falls more into the economic dimension. The concept of "Triple Bottom Line" (TBL), first introduced by John Elkington in 1997, offers a framework for performance evaluation of organizations that include not only the economic aspect but also environmental and social elements. According to Brønn and Brønn (2018), it provides a performance evaluation including values such as *fair trade* in the social dimension; *resource-use* and *consumption* in environmental; and *cost*, *growth*, and *revenue*, in economic features. However, several authors (Elkington, 1997; Goh et al., 2020; Goubran, 2019) claimed that the evaluation and quantification of the environmental and social dimension in TBL is a complex process that requires challenging changes in organizations.

3.1.2 Swedish Building Sector: Current Status and 2045 Roadmap

‘Sweden has committed to reducing greenhouse gas emissions to net-zero by 2045 and to pursue negative emissions thereafter, in line with its obligations to the Paris agreement” (Karlsson et al., 2020), and to achieve that, “there is an urgent need to start a transformation towards deep decarbonization” (Bataille et al., 2016). Seeing that the energy and climate performance of the user phase of the built environment in Sweden keeps improving, the climate impact of the construction process has increasingly come into focus (Peñaloza et al., 2018). According to Karlsson et al. (2020), such “impact of the construction process” - which mainly relates to the emissions arising from manufacturing, transporting, and processing of construction materials to buildings and infrastructure - accounts for approximately one-fifth of Sweden’s annual CO2 emissions, although “the current estimates contain significant degree of uncertainty” (ibid).



Within that one-fifth, 20% derives from transports infrastructure, while the building sector accounts for a considerably larger share, equivalent to 80%.

Those 80% derives mainly from annual emissions of cement-based products (32%), steel (17%), and fossil fuels (20%) that are used in construction processes and material transports. Remembering that in this accounting, not only materials but all building construction emissions are considered.

Other relevant emissions cited in the chart relate to insulation (8%), gypsum & plaster (5%), plastic & paints (3%), and others (15%), which corresponds to glass, aluminum, timber, etc.

Figure 3.1: Estimated CO2 emissions for building construction in 2019, from Karlsson et al. (2020)

On another analysis, emissions on base year 2015 are exhibited on building materials alone (A1-A3):

Emissions Estimate	Building Materials (A1–A3)	Transport (A4)		Construction Process (A5)
Updated estimate share of embodied emissions (%)	80%	9%	20%	11%
Updated estimate amount of embodied emissions (Mt CO_2)	6.3	0.7		0.9

Building Materials (A1–A3)	Concrete	Reinforcement Steel	Construction Steel	Insulation	Gypsum and Plaster	Plastic and Paints	Others (Glass, Aluminium, Timber)
estimate share of building material emissions (%)	40%	10%	11%	10%	6%	4%	19%

Table 3.1: Estimations cut from Karlsson et al. (2020)

Furthermore, data from the Swedish Environmental Protection Agency (Naturvårdsverket and Boverket, 2019) indicates that 2/3 of the construction emissions correspond to new buildings and 1/3 to refurbishments and maintenance. In addition, around 40–50% of the annual climate impact from building construction stems from the construction of non-residential buildings, such as offices, schools, and other premises. A growing share of around 40–50% arise from multi-family dwellings, and the remaining 10–15% from single-family houses.

In order to address such emissions, Sweden lived up to the ambitions of the Paris Agreement accord and approved in 2017 the climate pact law that entered into force in 2018 (Fossilfritt Sverige, 2018), setting the following goals and targets for the building sector in the coming years (indicated in Table 3.2).

Year	Boverket goals for CO_2 cuts (A1-A5)
2022	Buildings Environmental Declarations
2027	25% impact reduction relative to 2022
2030	50% impact reduction relative to 2022
2043	80% impact reduction relative to 2022
2045	Neutrality

Table 3.2: Targets, by authors, with data from Boverket

In response to these systematic roadmaps, the research conceived by Karlsson et al. (2020) investigated how these decarbonization targets could be achieved in practical ways, and it concluded supporting different future trajectories of technological developments for the supply chains. Such trajectories employ abatement measures by exploiting Biofuels, Electrification, Carbon capture and storage (CCS) and material efficiency, focusing on the production of materials and processes that poses the highest potentials for reductions.

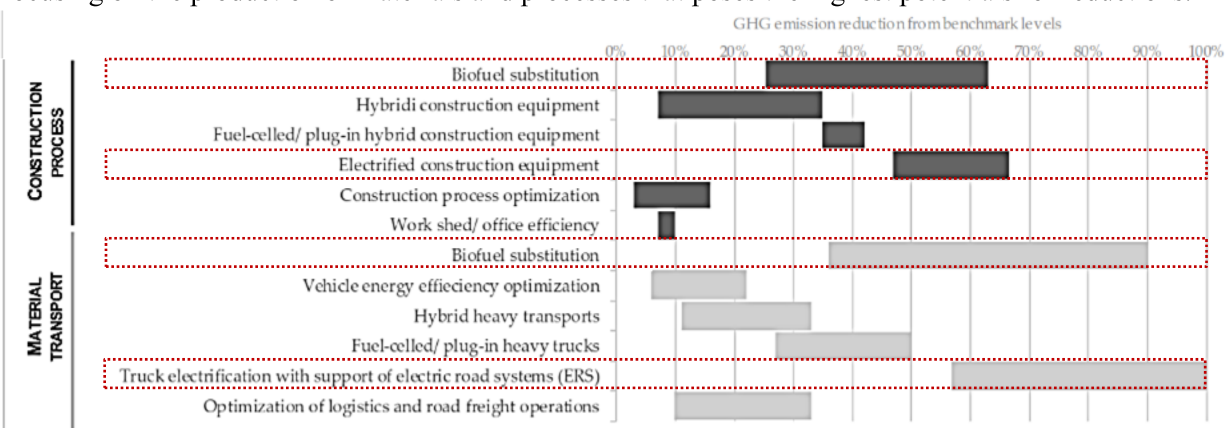


Table 3.3: Highest potentials for reductions in construction and transport, cut from Karlsson et al. (2020)

And on Table 3.4, the proposed 'construction equipment' and 'transport processes' pathways to attend the goal of 50% embodied carbon reduction by 2030, and 90-94% by 2045.

Material/Process	Pathway	2025	2030	2035	2040	2045
Construction equipment	All pathways	5% optimization	10% optimization	10% optimization	10% optimization	10% optimization
	Biofuel + CCS	42% biofuel 9% hybridization 5% electrification	63% biofuel 14% hybridization 9% electrification	78% biofuel 23% hybridization 13% electrification	85% biofuel 31% hybridization 15% electrification	81% biofuel 31% hybridization 19% electrification
	Electrification	42% biofue 19% hybridization 5% electrification	75% biofuel 14% hybridization 9% electrification	76% biofuel 23% hybridization 24% electrification	59% biofuel 23% hybridization 41% electrification	50% biofuel 23% hybridization 50% electrification
Heavy transports	All pathways	5% efficiency/ optimization	10% efficiency/ optimization	15% efficiency/ optimization	20% efficiency/ optimization	25% efficiency/ optimization
	Biofuel + CCS	42% biofuel 5% electrification	63% biofuel 10% electrification	78% biofuel 15% electrification	80% biofuel 20% electrification	75% biofuel 25% electrification
	Electrification	42% biofuel 5% electrification	63% biofuel 20% electrification	70% biofuel 30% electrification	55% biofuel 45% electrification	40% biofuel 60% electrification

Table 3.4: Pathway for abatement in equipment and transports over time, adapted from Karlsson et al. (2020)

Karlsson et al. (2020) conclude that, by applying the suggested measures, it is likely to reach near 90% emissions reductions by 2045, while energy may be decreased by fluctuating degrees (between 6 to 19% by 2030 and 16–37% by 2045), demonstrating that strategic routes may display varied implications on energy use over time. It is worth stating though, that "no pathway reaches zero emissions, evidencing it is important to tackle negative emissions strategies".

3.1.3 Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is a tool for assessing the environmental impact of a product or a system in quantitative terms of resource use and emissions that can be used for comparing different alternatives to examine if there is a potential improvement regarding environmental impact (Baumann and Tillman, 2004). According to RICS Embodied and WLC assessment for Architects report (2017), citing ISO 14040: 2006, LCA is essential to a WLC assessment and can be summarized as "a systematic set of procedures for compiling and examining the inputs and outputs of materials and energy, and the associated environmental impacts directly attributable to the functioning of a building throughout its life cycle". The product in an LCA model can be studied all the way from "cradle", meaning that the product is studied from the start of the production, i.e., raw material extraction, until "grave" which is the disposal. Conducting LCA includes four main steps (interdependent): goal and scope definition, inventory analysis, impact assessment, and interpretation of the results. LCA results can be used for decision making, research, product development, communications, etc. (Baumann and Tillman, 2004). The life cycle of buildings is divided into four main stages, product stage, construction process, use and end of life stage, as presented in Figure 3.2 (Jonsson, 2016).

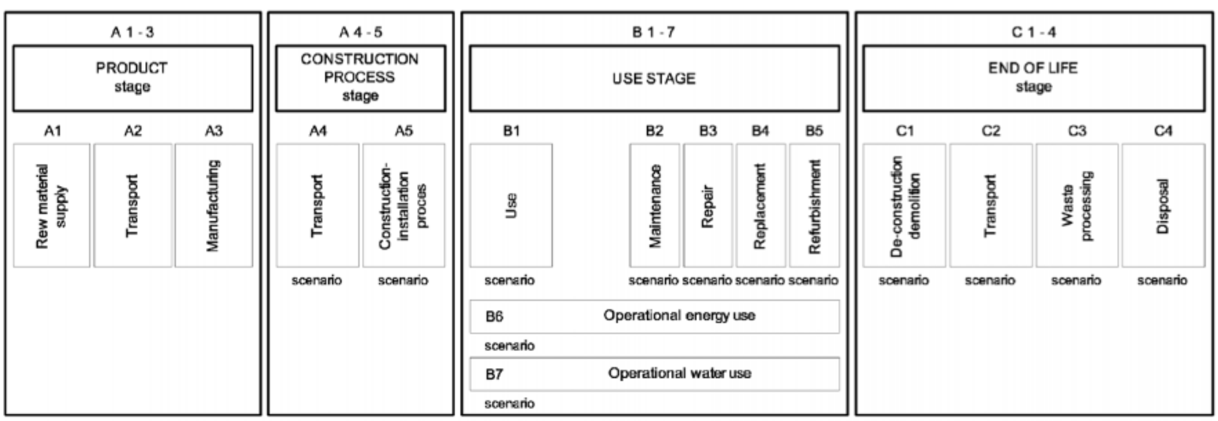


Figure 3.2: Life cycle stages of a building according to SS EN 15 804:2012+A1:2013 (Jonsson, 2016)

However, conducting LCA for buildings is not so simple. The first challenge, according to Beemsterboer et.al (2020) is that the demand for conducting LCA for buildings has been extremely low and thereby the knowledge is still on a low level. One of the steps in conducting LCA is the "Goal and scope definition" where an initial flow chart, including all flows related to the product, and allocation is done. The allocation can be challenging since there are usually multiple inputs/outputs, or multiple products that are produced and disposed/recycled at the same place. Consequently, the process of collecting data of materials and other resources for buildings can be complicated since there are a lot of different actors involved in each construction project. Geography is also one of the reasons this process is challenging, since calculations for transport of goods are unique for each project depending on where the project is located and what the circumstances are in that specific area (Beemsterboer et al., 2020). Time is another challenge in the process since the most accurate data can only be collected after the design phase is finished, which results in no room for changes or improvements, as illustrated Figure 3.3 (by the authors, inspired by UK-GBC (2017), and RIBA plan of work (RIBA, 2020)).

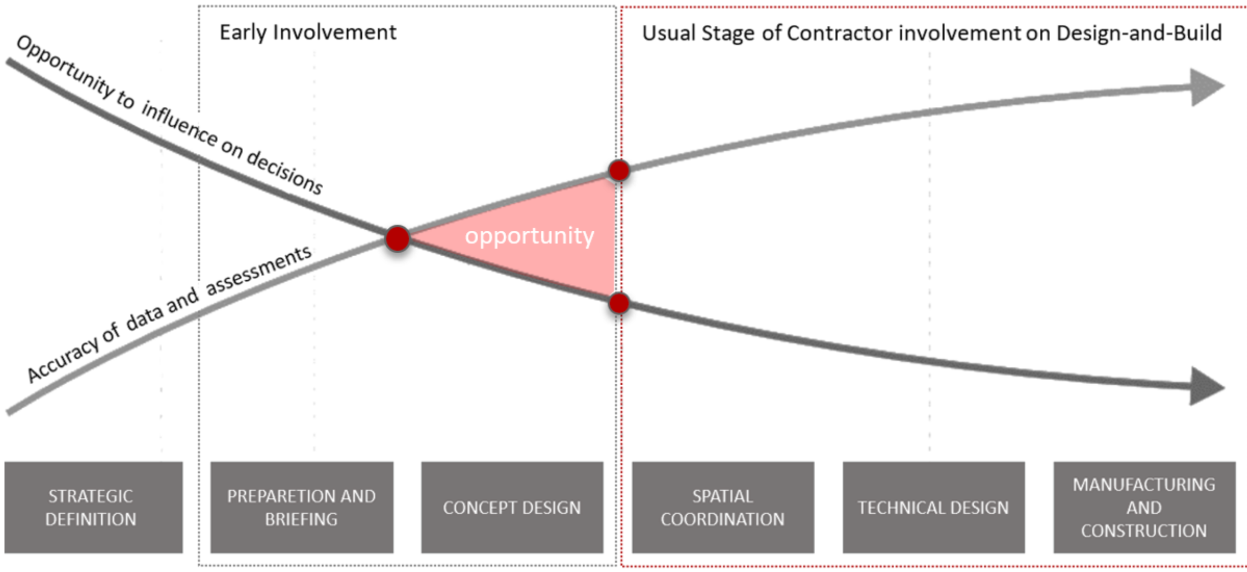


Figure 3.3: Assessments' accuracy vs ability to influence on time. Conceived by authors, inspired on UKGBC (2017) and RIBA plan of work (2020) stages

According to many authors (Beemsterboer et al., 2020; Karlsson et al., 2020), life-cycle calculations may end up with different results as assessments are poorly standardized. Choosing different methods (Beemsterboer et al., 2020) and using different assumptions (Karlsson et al., 2020) are some of the reasons why the results in LCA studies may differ. These different assumptions can lead to both overestimation and underestimation (Karlsson et al., 2020). Another common reason for flaws, according to Karlsson et al. (2020), is the complexity of the assessment tools, combined with insufficient training of engineers and architects. Attending to such issue, Beemsterboer et al. (2020b) present, between other simplified approaches, a pertinent one based in automation. It aims to provide different scenarios through data-based strategies. Such tool is known as 'OneClick LCA' and is also supported by other authors (Jonsson, 2019), as it provides different alternatives of environmental certifications through a simple process of building data input. Jonsson (2019) also mentions a tool called 'IMPACT', which is often used in the manufacturing prefabricated concrete elements and contains relevant data about materials and transports that can be useful to include in LCA calculations. Other than that, tools like 'Tally', as of authors' experience, allow users to imbue BIM data from materials, quantifying embodied impacts to land, air, and water systems in a more dynamic way.

3.1.3 Environmental Product Declaration (EPD)

Access to reliable data is essential to ensure the quality of assessment results. In this context, EPDs help to provide reliable information of a product's environmental footprint by analyzing and quantifying the impacts that this certain product produces. It takes into consideration the whole life cycle of a product and is a part of the series of ISO 14000 standards (Bovea et al., 2013). The purpose of EPDs is to describe a particular product's performance or a functional unit to compare different products (Jonsson, 2016) to provide transparent environmental information presented in quantitative terms in the form of indicators (Bovea et al., 2013). The process to develop an EPD includes four steps:

1. Product Category Rules (PCR) - different product categories for comparing LCA results;
2. Environmental product declaration draft – LCA of a product (quantified information of a product's life cycle in terms of raw materials, energy, emissions, etc.);
3. Verification process – third party verification;
4. Publication of the EPD.

According to the Swedish Standard Institute, cited by Jonsson (2016), the life cycle of a building has three different modules/, A, B, and C (Figure 3.2). Module A is divided into A1-A3 being is the product and A4-A5 being the construction process stage. Furthermore, module B is the use stage and is divided into B1-7. Module C is the End of Life of the product and is divided into C1-4. The declaration is conceived by the organization that owns the product through the use of Life Cycle Assessment (LCA), and the compliance with international and European standards guarantees transparency and accuracy of verified EPDs since those processes are carried by third-party accredited individuals or organizations.

There are many EPD programs and databases where EPD publications can be found, some of which are The International EPD® System from Sweden, KEITI-EPD from Korea, and IBU-EPD from Germany (Bovea, Ibáñez-Forés and Agustí-Juan, 2013). These three mentioned programs have the largest number of EPDs, while the Swedish program has the largest number of PCRs. Although most of the EPD programs include PCRs for construction products, there are some programs developed specifically for construction and building materials and/or systems, such as IBU-EPD and BRE from the United Kingdom.

Moreover, initiatives such as RICS, Whole Life Carbon Assessment for the build environment report (2017), and the ECB Study10 (Simonen et al., 2017), benchmarked assessments, providing magnitude and range for the embodied carbon impact in buildings. According to UK-GBC *Embodied Carbon – Developing a Client Brief* report (2017), understanding buildings' performance in relation to others can assist in making the assessment more meaningful. Such understanding is supported by relevant international players such as RIBA through their *Plan of Work* report (2020), RICS *Whole Life Carbon Assessment* report (2017), and others. In Sweden, authorities such as Boverket are conceiving a database for climate declarations and are expected to support the upcoming Government's proposal for law and ordinance on climate declarations for buildings, in compliance with *the Climate Declaration Act* (2019), coming to effect in January 2022.

3.1.4 Multi Criteria Decision Analysis (MCDA)

Although embodied carbon has been increasingly prioritized in this study, there are other relevant criteria when it comes to buildings. A few authors emphasize the importance of including multiple objectives such as environmental impact, stakeholders, and long-term effects in the process of decision-making (Campos-Guzmán et al., 2019; Keeney, 1982; Zanghelini et al., 2018). Multi-Criteria Decision Analysis (MCDA) has been increasingly used to deal with energy, materials, environment, sustainability, quality and supply chain management, production management, etc.

As discussed in chapter 3.1.3, the LCA is objective as it studies the potential environmental impact of a product's life cycle. At the same time, the MCDA is subjective since it includes multiple objectives such as stakeholders' and decision makers' opinions (Zanghelini et al., 2018). Furthermore, LCA and MCDA are interrelated and are complementing each other. For instance, LCA can be used as criteria in MCDA, and MCDA can be used in the different processes of the LCA, such as the inventory analysis or interpretation of results.

Life Cycle Costing (LCC) can also be a part of the MCDA when including an economic perspective. As described by Yang et al. (2020), LCC is an evaluation of the economic life cycle of a product or service as a sum of initial cost, operating cost, and discarding cost. However, according to Zanghelini et al. (2017), LCC is rarely present in the literature as criteria in decision analysis.

3.1.5 Embodied-Carbon to practical completion (A1 - A5)

The energy consumptions in buildings consist of two types being embodied and operational (Cabeza et al., 2014). The raw material used to manufacture products and for construction on-site, both depending on transportation is linked to the embodied energy consumption. The operational energy consumption is associated with the maintenance of the building, including heating, ventilation, appliances, lighting, etc. Statistics over the construction- and building sector's CO2 emissions from 1993 to 2018 are illustrated in Figure 3.4 (Boverket, 2021). The figure indicates that operational impact has been decreasing over the years, also supported by the UK-GBC (2017), whilst embodied carbon impact has slightly increased.

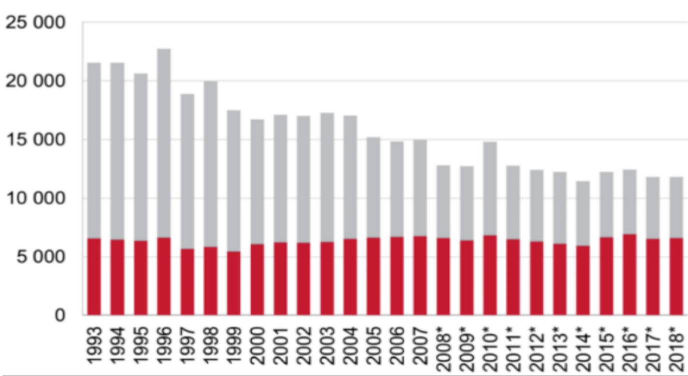


Figure 3.4: Emissions from the infrastructure and building sector in thousands ton. of CO2eq (Boverket, 2021). *In grey: CO2 for heating. In red: CO2 Emissions excluding heating.*

Following that understanding, Sweden demands climate declarations for new buildings, coming into force through regulations by the 1st of January 2022 (Boverket, 2020a). These declarations are supposed to provide data on CO_2 emissions for buildings, initially from the product and construction process stage (A1-A5) - also known as *embodied carbon to practical completion* - and later on, for the whole lifecycle.

The legislation aims to reduce environmental impact from buildings to meet the systematic targets for 50% reduction by 2030 and neutrality by 2045 (previously addressed in chapter 3.1.2). Regarding operational impact, Sweden provides investment aid for new buildings and reconstructions, when it is for rental apartments in regions with housing shortages (Sveriges Allmännytta, n.d.). As stated by Sveriges Allmännytta (n.d.), the fundamental requirement for this investment aid in the energy performance of the building, which should not exceed 56% of building's BBR's requirements.

3.2 Buildability

3.2.1 Theoretical definition

According to Moore (1996), buildability was marketed as an approach to overcome the construction industry problems in the early '80s, and different definitions for the concept were championed. One widely accepted version, created by the Construction Industry Research and Information Association (CIRIA) in 1983, stated that "buildability is the extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building" (Wong et al., 2006). Since then, the term 'ease of construction' has been used by several researchers exploring buildability (Chen et al., 1991; McGeorge et al., 1992; SEAB, 1993; Chen and McGeorge, 1994; Low and Abeyegoonasekera, 2001; Low, 2001; Lam, 2002; Wong et al., 2011).

Additionally, other authors, particularly from the USA and Australia, made use of the essentially analogous term 'Constructability' as "the optimum use of construction knowledge" (CII, 1986) and "the integration of construction knowledge in the project delivery process" to achieve performance and project goals (CII Australia, 1996). Such references, although not labeled as 'buildability', explicitly remark the importance of knowledge transfer from production back to design, and as such, are quite pertinent to this study. In fact, although a few authors (Wong et al. 2011) see buildability and constructability as different concepts - the first a design strategy, while the second a holistic approach - many others support them as equal, with the only difference being credited to the region where each term is used (Alzayd R., 2016).

Nonetheless, the relevance of production knowledge in design goes way back. CIRIA (1983), for instance, argued that "building clients were not being allowed to obtain value for the money due to the separation of the design and construction functions". To address such issues, professionals from these different stages should look at the whole construction process "through each other's eyes" (ibid). Illingworth (1984) further supported a joint exercise of study between designers and contractors, and Moore (1996) claimed it is "not solely about the technicalities of the construction process", but "a problem of managing the transfer of appropriate knowledge about the construction process to the design process worker". Accordingly, many researchers argue for a closer relationship between designers and builders, supporting communication and shared knowledge (e.g., Emmerson, 1962; Banwell, 1964; BRS, 1970; RICS, 1979; Illingworth, 1984; and Jarkas, 2010). Wong et al. (2011) added that as earlier in the project buildability principles are addressed, the easier it is to influence the project outcome through a more efficient use of resources, consequently improving indicators such as cost, quality, and safety performance - which are often perceived as major success factors. It is noted, however, that environmental criteria do not play a central role within most buildability articles - especially the older ones. It seems that only CIIA (1992) directly mention 'environmental constraints', when referring to 'Constructability'. More recently, however, a number of 'Buildability' papers (e.g., Simonsson, 2011; Natee et al., 2011; Mathern A., 2019h; and Linderfalk A. & Ljungqvist S., 2020) directly link it to 'Sustainability'. Nevertheless, one could argue that many principles endorsed in buildability directly promote sustainability. As so, the potential of this association is further developed in chapter 3.2.4.

3.2.2 Principles

When studying buildability, it is important to acknowledge what ‘technicalities of the construction process’ are believed to provide the so-called ‘ease-of-construction’, since that is undeniably a subjective topic. To tackle such issue, this study presents a list of principles that are supported through literature to achieve that.

A literature review followed by a survey conducted by Wong et al. (2011), provides a list of ‘Buildability Factors’ (BF), that serves to clarify such principles as of this study viewpoint (Table 3.5).

BF1: allowing **economic use** of plant and labor skills
BF2: **standardization** and **repetition**
BF3: allowing optimal mix of **prefabricated** works and on-site work
BF4: allowing adaptation by contractor on site without extensive rework
BF5: updated and coordinated design documents
BF6: simplifying and streamlining nontypical building designs
BF7: facilitating temporary works
BF8: designing to suit site conditions
BF9: enabling efficient site layout, storage, and site access
BF10: designing for available materials, fittings, products, and subassemblies
BF11: designing to avoid adverse weather
BF12: designing for safe sequence of trades
BF13: allowing visualization of finished work
BF14: accurate positioning of pipe sleeves and penetrations
BF15: allowing innovative construction techniques
BF16: allowing for a wide range of materials

Table 3.5: Buildability factors

As of this list, it can be observed that the three first factors are somewhat related to assembling, prefabrication, repetition, and hence, manufacturing. Moreover, Wong et al. (2011) further argue for design approaches “enabling freedom of choice between prefabricated and on-site works”, as well as the “simplification of construction details”, which are also relevant in terms of contractors flexibility to propose an industrialized approach. As a matter of fact, almost all buildability papers reviewed in this study mention standardization and manufacturing methods as part of an *easier construction*. Consequently, a Design for Manufacturing (DfMa) approach is often advocated.

3.2.3 Buildability as a drive for Sustainable Construction

As previously mentioned, Sustainability is not traditionally the focus of buildability strategies. Essentially, the concept focuses on ‘ease of construction’ to achieve ‘economic’ project factors, such as cost, time, and safety (Gray, 1983). It seems clear, however, that buildability principles fostering ‘resource efficiency’ and ‘waste reduction’ (table 3.5), will consequently also reduce the impact on environment.

In fact, evidence brought by Karlsson et al. (2020), referring to other studies, suggest that around one-third of all material used in construction could be spared if designs were optimized for efficient use rather than the usual fast-paced downstream that prioritizes labor costs. For instance, using a standardized cross-section is faster than designing each beam and column individually, as well as cheaper to manufacture and simpler to build (ibid). Moreover, many products experience higher loads during transport or assembly than in actual use (Giesekam et al., 2014), and the costs of eventual failures are higher than the ‘safety margin’ typically applied on over-specifications. Thus, the use of extra materials is cost-driven.

In harmony with that, Mathern A. (2019) claims that the economic dimension of Sustainability is connected to Buildability via construction costs. According to him, however, while Buildability is more centered on reducing risks for cost-overruns, the 'economic sustainability' concerns the probability and size of these costs - with respect to the risk of turning it unfeasible, and hence unsustainable.

As of feasibility, the roadmap by Karlsson et al. (2020), reviewed in chapter 3.1.2, mentions strategies to meet the ambitious embodied carbon targets established by Swedish authorities. Thus far, currently, the only envisioned strategy arguably 'able' to reach carbon neutrality by 2045. It seems clear though, that the ploy based on electrification, biofuels, and carbon capture, will come with its costs (WSP, 2021).

3.2.4 Challenges and Opportunities

It has been argued that an attempt to impose "predetermined construction solutions" endorsing buildability would not be willingly accepted by designers (Moore, 1996). It has been argued that an attempt to impose "predetermined construction solutions" endorsing buildability would not be willingly accepted by designers (Moore, 1996), especially since concepts such as 'repetition', 'rationalization' and 'standardization' are generally seen as threats to designer's creativity and relevance (Lawson, 1986; Moore and Tunnicliffe, 1994). In fact, Higgin & Jessop (1963) claimed that 'maximum architectural magnificence' is often sponsored at the expense of technological considerations.

Despite of that, however, a survey conducted by Peter Simonsson in 2011 has supported that 'Designers' are the project-actors with the biggest potential to influence buildability (Figure 3.5). The research, which considered the opinions of 'Clients', 'Contractors' and 'Designers' in Sweden, evidenced how relatively limited is the Contractors power to affect the Project's buildability (13%).

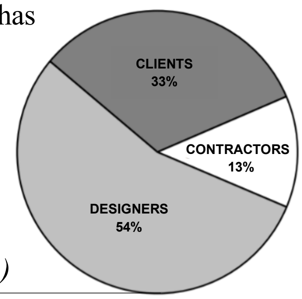


Figure 3.5: Project-actors potential to affect Buildability, from Simonsson (2011)

In harmony with that, Simonsson (2011) study demonstrated that the top factor pointed out by Contractor's respondents influencing buildability in Sweden is the 'Early involvement of Contractor'. On the other hand, 'Designers' ranked EIC on 4th place, while 'Clients' surprisingly ranked it only on 7th. In respect to that, Simonsson (2011) reasoned that, possibly, clients believe to "have the competence themselves".

These issues contributed to new project delivery strategies in which the responsibility for design is passed to the builder. According to Moore (1996), the so-called 'Design-and-Build' can be seen as a procurement approach to provide contractor's independence, granting more flexibility to propose 'ease of construction' solutions early on project development. However, as argued by Gray (1983), no simple answers exist to the implications of design, and consequences vary from distinct factors (e.g., cost, time, and safety). Such complexity is aggravated since decisions must be taken "within the time frame of the design team's thinking". Hence in that case, designers are even more pressured as construction is already underway, and as a consequence, decision making is often carried without proper considerations.

In fact, Moore (1996) related an increasing concern over the quality of building designs resulted from the DB procurement route, reasoning that on contractor-led Design-and-Build, cost certainty is often achieved "at the expense of design quality". Moore (1996) hence suggests a "range of strategies" to be approached concurrently, dealing with diverse buildability aspects in ways that designers "are able to try out alternatives on a 'what-if' basis", trusting that development time can be reduced while not imposing preset solutions.

Concerning buildability strategies, an interesting case is the Singapore's government evaluation scheme. It established a requirement for early evaluation of buildings designs performance through 'buildable design appraisal system' (BDAS), 'constructability appraisal system' (CAS), and 'green mark scheme' (GMS). A minimum buildability score is required to be met according to certain criteria and building categories (BCA Code of Practices on Buildability, 2017). However, Nate et al. (2011) claim that, although Singapore's system tackles environmental, buildability, and constructability principles, it does not comprise many other important criteria required by buildings stakeholders, such as aesthetics, costs, or building durability. Therefore, performing well in the actual score system not necessarily imply in the success of the project or on stakeholder's satisfaction (ibid).

Suitably, Moore D. (1996) have asked back in 96' "how much information of the construction process, and in what form, does an individual design worker require?" - *One could well add today: 'when' is it required?*

3.3 Buildings Procurement

In this subchapter, different types of regulations regarding buildings, private and public procurement as well as a broader description of the procurement methods is presented.

3.3.1 Buildings Regulations in Sweden

The regulatory hierarchy for construction and buildings in Sweden is consists of three levels (Boverket, 2020b): Planning and Building Act (Plan- och Bygglagen, PBL), Planning and Building Ordinances (Plan- och Byggförordningen, PBF), and Boverkets Building Regulations (BBR) and European Construction Standards (Europeiska Kostruktionsstandarded, EKS).

PBL is adopted by the Parliament, contains 16 chapters regarding planning for land and water area and construction, and includes basic requirements for all construction works, new buildings, moving buildings, and changing buildings (Boverket, 2020b). Above PBL is PBF, which is adopted by the Government and includes some more specific requirements than those in the Act.

BBR applies only for buildings and sometimes for sites (Boverket, 2020b). The regulations are designed in the form of performance requirements, meaning that the performance of the buildings and buildings components are required to fulfill a specific function. However, BBR doesn't only consist of performance requirements but also provides recommendations (not legally binding) of technical solutions that can be used and thereby giving the contractor freedom to be innovative and choose other technical solutions.

3.3.2 Public and private procurement

In Sweden, the public procurement is regulated by The Public Procurement Act (Lagen om Offentlig Upphandling, LOU). All state and municipal authorities must follow LOU when procuring supplies, services or works, and when organizing a design contest by awarding the supplier/contractor with a contract (Swedish Competition Authority, 2016). The contract itself is, in other words, a written contract of interest of the objects that are to be executed. Regarding the construction industry, this legislation must be followed by the authorities when procuring new contracts, be that under Design-Bid-Build or in Design-Build route.

The public procurement Act's purpose is to enable equal treatment for all competitors and to ensure that the clients doesn't only go for the lowest price but that they take into consideration other value-adding factors such as environment, quality, cost-efficiency, functional and technical characteristics (Bröchner and Kadefors, 2009). The process of public procurement starts with the client developing a briefing with different requirements regarding the project that is going to be procured and deciding the procurement method to announce it for the contractors as a request for bidding (Kammarkollegiet, 2010). After all contractors have left their bids, the client is evaluating the bids (according to LOU) and choosing one contractor to sign a contract with. However, there are some disadvantages in public procurement for smaller companies to compete, for instance, if there is a lack of knowledge for LOU, then the bidding process can become too complex, time pressure due to lack of resources, the traditional way by choosing the bid with the lowest price instead of the most valuable (Bröchner and Kadefors, 2009).

Private procurement, in comparison to public procurement, doesn’t require tendering (Nilsson, 2006), is more flexible, and therefore private actors often develop their own regulations, similar to the ones that apply for public procurement (Bröchner and Kadefors, 2009). Furthermore, Nilsson (2006) mentions that procurement within the private sector in Sweden is mostly based on client's relationships and experiences with different contractors.

3.3.3 Framework for documentation

As mentioned in chapter 3.3.2, the client is announcing a request that the contractors can take a part of to calculate a price and send a bid. The request should be as clear as possible and the requirements should not be too low or too high to keep it competitive and to avoid misunderstandings (Kammarkollegiet, 2010). In Sweden, there is a systematic contractual framework with regulations for the construction and building industry to be used in public procurement called AMA AF, where AF stands for Administrative Regulations (Administrativa Föreskrifter in Swedish). AMA AF contains of different sections, each section containing of different codes. The content of AMA AF is shown and described in Table 3.6.

AMA AF	
AFA	Information about the orientation of the construction project such as what is going to be built, where it is located.
AFB	Information about procurement regulations such as the type of procurement and contract, if there are any criteria for contractors and subcontractors etc.
AFC	Information about construction regulations in DBB contracts such as conditions for the construction work, requirements regarding quality and environmental management, remuneration etc.
AFD	Information about construction regulations in DB contracts
AFG	Information about general work and utilities

Table 3.6: Sections in AMA AF, summarized from Kammarkollegiet (2010), & Stadsbyggnadsförvaltningen (2015)

3.3.3 Quality and environmental management standards

The International Organization of Standardization (ISO) provides with different standards for products and services, such as ISO 9001, the standard for quality management systems, and ISO 14001 the standard for environmental management systems.

ISO 9001 is based on the quality management principles of ISO 9000, which are: customer focus, leadership, engagement of people, process approach, improvement, evidence-based decision making, and relationship management (ISO, 2015a). The purpose with ISO 9001 is to improve the overall performance of organizations as well as to set the basis for sustainable development by implementing process approach and risk-based thinking.

The need of implementing environmental management systems has been increased due to inefficient use of resources, waste management, and increased emissions (ISO, 2015b). ISO 14001 provides a framework of environmental management systems for balancing the socio-economic needs with a systematic approach.

3.3.4 Tendering and Client Requirements

There are different ways to express client requirements through tender documents.

'Functional requirements', as stated by Trinius and Sjöström (2005), regards "fitness for purpose", and relate to the scope and expressions of user-requirements "containing aspects of functionality, quality, comfort, efficiency, etc." To be operational, "these expressions of requirements must be transformed into assessment" (Trinius and Sjöström, 2007), which in this case, are the 'Technical Specifications' comprised in tender documents.

'Technical Specifications', according to the European 'Procurement Directive 2014/24/EU'(SOU, 2019), defines "the characteristics required of a material, product or supply, so that it fulfills the use for which it is intended" (its functional requirement), and thus it can include several specifications such as levels of environmental and climate performance, drawings for functional requirements (e.g., accessibility), general performance, safety, procedures of quality assurance, testing, user instructions, production processes, overall details, etc. Moreover, these are typically approached in two forms: 'Prescriptive' and 'Performance'.

'Prescriptive Requirements' are written specifications and design-drawings that define what needs to be delivered, and ***how*** it is to be delivered. It focuses on describing the solutions rather than expected outcomes.

'Performance Requirements', on the other hand, defines the requirements in terms of "measurable outcomes or objectives", focused on "what needs to be delivered, but ***does not detail how*** or specific solutions".

In regard to the different forms of requirements, it has been argued that "requirements in private and public procurement processes can have a large impact in steering designers, contractors, and suppliers towards choosing smarter solutions", and one way of improving tenders and project outcomes is through "stretching performance requirements" and giving "economic incentives" for overperformed requirements (WSP, 2021). In other words, "the state defines what properties a building should have" but leave the solution choice to others (SOU, 2019).

According to the recent report by SOU (2019), there exists "many ambiguities throughout the regulations" that lead to distinct interpretations, which in turn has made "efficient construction more difficult and costlier" and left "very limited room for innovations and variations in construction". An example of this ambiguity is shown in 'Special Requirements', a term that has been increasingly recognized by the Swedish Construction industry as a set of requirements that are - more often than desired - added by Clients on top of 'standard agreements' (e.g., ABT06). Such practices have been unencouraged and even banned by the 'National Board of Housing, Building and Planning', considering that 'standard agreements' should be enough. Despite that, 'Special requirements' are still adopted by diverse Municipalities (SOU, 2019).

The previously cited report was conceived by the 'Committee for Modern Building Regulations', appointed in 2017 by the Swedish government with the task of "modernizing and simplifying regulations, promoting increased housing construction and increased competition, without compromising health, safety, quality of design, a good living environment and long-term sustainable construction". Between the many interesting proposals, the committee suggests a new authority, named 'the Building Requirements Board' to facilitate industrialized construction. It also supports that "general advice and references to standards in BBR should be removed", as well as "recommendations that can be interpreted as rules", since municipalities often follow them as such. Further, it claims that the new established board should be tasked to assess "whether certain technical solutions meet the set functional requirements", since "in some cases it is difficult to show that the functional requirements are met if the general guidelines have not been followed".

In resume, this section shows that existing building procurement laws in Sweden are complex, often leading to uncertainties and inefficiencies. Yet, the matter is clearly acknowledged by competent authorities, and much new information concerning ongoing law changes is found on 'Boverket' page and other sources.

3.3.5 Procurement Methods

There are different procurement methods in construction projects, but the most common are Design-Build and Design-Bid-Build. Additionally, Partnering is a procurement practice that counts with a collaborative approach and has gained attention from the construction industry.

Design-Build (DB) contracts, called "totalentreprenad" in Sweden, is a procurement method where the client develops a briefing where the project's scope is defined, which usually consists of pre-design. The contractor is responsible for both design and construction and, in some cases, responsible for the maintenance (Borg and Lind, 2014). Accordingly, the contractor is involved in the project right after the pre-design is developed. As stated by a few authors (Borg and Lind, 2014; Eriksson et al., 2019), this procurement method gives more freedom to the contractors by allowing them to use innovative technical solutions to improve project performance. In Sweden, there is a standard agreement (standardavtal) developed for DB contracts, called ABT06, General Conditions of Contract for design and construct contracts for buildings, civil engineering, and installation work (Byggandets Kontraktskommitté, 2006).

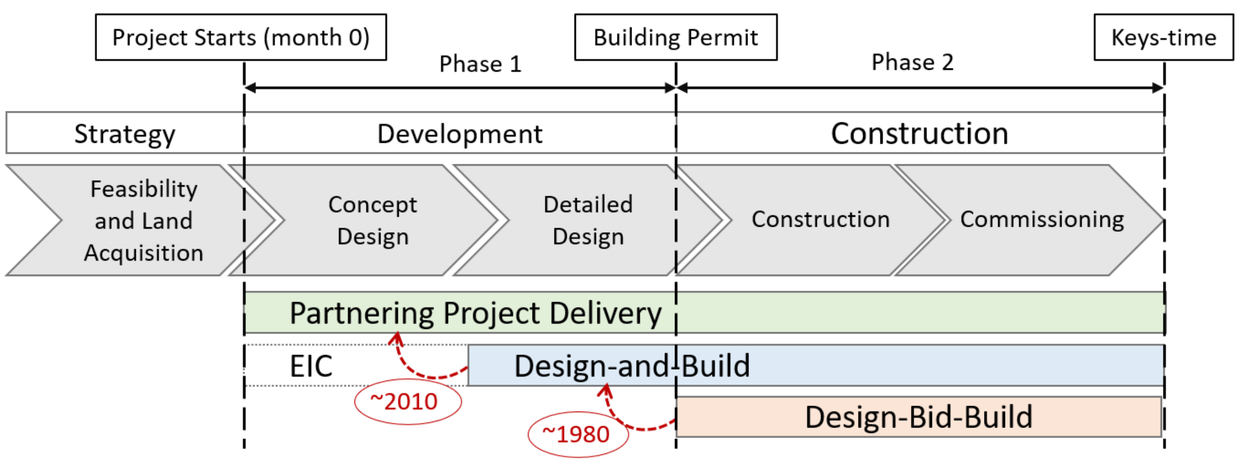


Figure 3.6: Project stages and procurement routes, conceived by authors

On the other hand, in Design-Bid-Build (DBB) contracts, the client, together with consultants, develops up to the technical design, and the contractor's responsibility is uniquely to execute the construction (Borg and Lind, 2014). That way, the client has more control of the project resulting in limiting the contractor's freedom. The standard agreement (standardavtal) for DBB contracts is the AB04 (Byggandets Kontraktskommitté, 2005). The standard agreements for DB and DBB contracts are developed to have "a reasonable balance between rights and obligations" for both parties (Byggandets Kontraktskommitté, 2006, 2005, p.3). Further, these provide regulations and advice while at the same time allowing clients and contractors to agree on other terms. For both DB and DBB contracts, the client uses a competitive tendering process (Borg and Lind, 2014), where usually, the contractor offering the lowest price in the bidding is awarded a contract. Furthermore, both of these procurement methods are associated with the fixed-price payment method, limiting collaboration between the client and the contractor (Eriksson et al., 2019).

Alternatively, on Partnering's project delivery, customarily, a probable cost of a specific scope of work is estimated and defined as a 'target price'. At the same time, financial incentives are given for better performance goals (Kadefors and Badenfelt, 2009). In a first, development phase, these conditions are agreed through 'EIC' and adjusted for changes during the second, construction phase (Blad and Johansson, 2015). In general, 'Partnering' approach to project delivery is seen as a "straight-forward way to achieve improved targets" (CIPFA, 2013) through "trust and mutual understanding" (Linderfalk and Ljungqvist, 2020) enabling through the "integration of contractor's knowledge in early stages" (Simonsson P., 2011) an "increased Constructability in Design" (Eriksson et al., 2019). However, 'Partnering' is particularly used when the construction project is more complex and there is more uncertainty (Kadefors, 2002), since ahigher flexibility and collaboration is especially sought (Bower, 2003).

It is important to note, however, that such conditions are especially true for public procurement. In the case of private 'Clients' (developers), since the 'Public Procurement Act' is, of course, not a demand, there is hence no need for procurements through public tenders (chapter 3.3.2). Thus, the service provider (Contractor) is often involved earlier and chosen based solely on their relationships and previous experiences (Nilsson, 2006). Contrary to that, public clients are obliged by force of law to follow 'LOU' guidelines and hence cannot arbitrarily choose their partner or collaborate before the tender.

Ultimately, the contractual framework for partnering in Sweden is usually based on and similarly developed as AB04 and/or ABT06 (Enjebo & Guldbranzén, 2014).

3.4 Technologies

3.4.1 Optical Character Recognition 'OCR', or 'PDF-reading' tool

According to Mainkar et al. (2020), citing Roby et al. (2020), 'Optical Character Recognition' (OCR) is one of the techniques that convert the scanned or printed image document into an editable text document. Sarkar (2004) claimed that OCR technology allows for the conversion of a captured image into a machine editable data, and Mainkar V. & Katkar J.A. (2020) added that it does the work in 3 stages. First, scanning the document; Second, recognizing characters, words, and lines; and third, storing these in the desired structure.

This study supports these 3 stages approached in 5 methodological steps, the first is the 'Image Acquisition' from the physical document or image (scanning process), so that it can be further subjected to image processing techniques. This can be done through a scanner device or a phone. In the second step, 'Pre-processing' encompasses diverse application specific techniques to make the image suitable. In the third step, 'Line, Word and Character Segmentation', the characters are segmented into lines and words, so that it can be recognized easily. In the fourth step, 'Feature Extraction', individual characters are cropped, and their features are extracted. For each character, a 'feature vector' is created, defining its shape and characteristics so it can be distinctively identified. Lastly, the fifth step, 'Classification': assigns meaning to the segmented characters, providing an editable format as recognized output. To provide superior precision it has been advocated the use of diverse methodologies. A recent model, revealed by Zhang et al. (2020), successfully obtained more than 98% accuracy by suggesting a novel approach, training the 'Graph Neural Networks' (GNN) only by documents datasets, and then further generalizing it to new ones (ibid).

3.4.2 Floor plans Raster-to-Vector - 2D & 3D

Similar to the previously mentioned character recognition technology, a source input in form of a raster-image (usually scanned), possibly from the original floorplan drawing in a PNG file format, or other, can also be recognized using different existing methodologies. According to Kalervo A. (2019), current state-of-the-art models in automatic floorplan image analysis have mostly been using deep 'Convolutional Neural Networks' (CNNs). Yet, one issue of such approaches to vectorize these raster images into CAD, or even 3D models, has been challenged by the limited amount of floorplan datasets for these deep learning models to actually learn from. However, Kalervo A. (2019), recently presented in a study, very accurate results using a cutting-edge Finish dataset named 'CubiCasa5K' "with 5.000 floorplans collected and reviewed from a broader set of 15.000 images". Such results can be observed in Kalervo A. (2019).

3.4.3 Genetic Algorithms (GA) – applied for Buildability

Goodfellow et al. (2014) pioneered the field of 'Generative Adversarial Nets' (GAN) with complex possibilities. Further, Isola et al. (2018) enabled image-to-image translation and explored generation of building façade, returned by Andrew Witt (Chaillou, 2019). Furthermore, current uses of 'Computational Design' in tools such as Dynamo, Rhino, as well as more recently 'SpaceMaker AI' and others, evidenced the enormous potential of such technologies to explore 'Buildability' solutions, such as crane positioning, scaffoldings, and other construction concerns. Further, it opens possibilities for decision making to be approached analyzing best possible solutions using a larger amount of multi criteria input parameters.

4 Empirical Findings

In this chapter, the empirical data is presented. As previously explained, the empirical research is divided in three parts, being the first an analysis of tender documents provided by the organization in study; followed by interviews with Industry representatives; and lastly a survey with a similar but wider sample.

4.1 Documents analysis

One of the assumptions from this research is that 'client requirements' - which are specified by terms and drawings in tender documents - have a great influence on the current buildability suboptimization, possibly promoting inefficient practices. Therefore, twelve different building tenders from 2019 and 2020 provided by the studied organization have their documents and comprised requirements analyzed in this chapter.

A first analysis, presented in Table 4.1, shows the kind of tender documents that appear to be most frequently provided by the clients.

Documents (Swedish)	Documents (English)
Allmäna föreskrifter	General Regulations
Teknisk beskrivning	Technical description
Rambeskrivning Stomme	Framework description for Structure
Rambeskrivning Akustik	Framework description for Acoustics/Noise
Rambeskrivning Bygg	Framework description for Construction
Rambeskrivning Ventilation & Styr	Framework description for Ventilation and Control
Rambeskrivning Mark	Framework description for Ground
Rambeskrivning El & Tele	Framework description for Electricity and Telephone

Table 4.1: List of documents analyzed

A second analysis focus more specifically on the type of requirements that possibly affect buildability and sustainability and is presented in Table 4.2.

	Clients Requirements on Procurement Contracts		Tender 1	Tender 2	Tender 3	Tender 4	Tender 5	Tender 6	Tender 7	Tender 8	Tender 9	Tender 10	Tender 11	Tender 12	Presence [%]
		Procurement type	General contract	Collaboration	Not defined	DB	DB		General contract	DB			Not defined		
		Contract type	DB	DB	DB	DB	DB	...	DB	DB	DCM		DB		
		No.													
1	**Comply with AMA AF 12**		x	x		x	x		x	x	x		x		66.7
2	**Criteria for tenderers**		x	x			x		x	x	x		x		58.3
3	**Criteria for subcontractors**		x			x	x			x	x		x		50.0
4	**Certified with ISO 9001 (quality)**		x				x		x	x			x		41.7
5	**Certified with ISO 14001 (environment)**		x				x		x	x			x		41.7
6	**Environmental certification**					x	x	x							25.0
7	**LCA**		x			x	x	x							33.3
8	**LCC (on specific object)**												x		8.3
9	**Social issues at Production**		x					x							16.7
10	**Materials Toxicity**							x	x					x	25.0
11	**Materials choice requirement**		x			x	x	x		x	x		x		58.3
12	**Acoustic requirements**							x	x	x		x		x	41.7
13	**Thermal requirements**								x	x					16.7
14	**Structural framing system requirements**					x					x	x	x	x	41.7
15	**Building components requirements**					x	x	x		x	x	x	x	x	66.7
16	**Energy consumption requirements**		x			x	x	x	x				x	x	58.3

Residential
Corporate
Educational
Other

Table 4.2: The frequency of different 'client requirements' in the studied tender projects

The typology of the building, the type of contract, and possible collaborative approach are presented in the top-colored part of the table. This process of searching for the requirements was done by searching for keywords of the specific requirements in all different tendering documents provided by the client in each project. Some of the requirements are simple to be interpreted, such as the ones that determine if a standard or a framework is being followed, while some include a higher level of detail and complexity within. A few requirements that can be highlighted, since more frequently present in these documents, are 'building components', with 66.7%, 'materials', with 58.3%, 'energy consumption', with 58.3%, 'structural framing', with 41.7%, as well as 'acoustic', with 41.7%. Furthermore, a thorough explanation about how each requirement is presented in the document's, and comments regarding their connection to this thesis, is presented in Appendix I.

4.2 Interviews (Qualitative approach)

The data retrieved, from transcriptions of recordings and notes, from the discussions of the interviewees' experiences from all interviews, was thematically divided in three parts and is presented in this chapter. The interviewees names, organizations, roles, and regions are presented in Table 3. However, in this chapter the interviewees are not named whenever citations are used for ethical reasons (see Chapter 2.5). Further, the data collected from interviews is presented through a narrative, making use of eventual quotes using interviewees original, words. In here, it is important to emphasize that, as of the approach designed in research method, the main goal of the interview is to build a broad awareness, and so, inform the survey.

4.2.1 Theme I: Early Involvement of Contractor (EIC), Collaboration and Partnering

It seems clear that many authors support that one way of improving buildability, reducing climate impact, and delivering an overall more valuable construction product, is through a higher collaboration between the different project stakeholders. Grounded on some of the first findings from the literature review, the first part of our interview confronts respondents with questions regarding EIC, Collaboration, and Partnering.

Concerning that, most interviewees mentioned that they could more often work with early involvement with private clients and thereby can influence the tender briefing before it is announced. There are, although, certain details in terms of competitive ethics. For instance, a too close relationship with the client might end up be seen negatively by other contractors, resulting in these other contractors not participating in future tenders with that certain client (believing it is just loss of time). Regarding this, more than one interviewee mentioned that this is also true when it comes to sub-contractors. If they, as general contractors, count with the early involvement of a supplier – i.e., a ventilation expert – to help creating the solution from '*scratch*', and then this specific ventilation company recurrently wins the tenders to supply for them on new contracts, then other ventilation suppliers will eventually give up on sending in their bids, as it might appear as a 'game of preset cards', with a known winner.

With public clients, on the other hand, there are bigger legal barriers for EIC, since the Public Procurement Act (LOU) establishes equal treatment for all contractors, and if one contractor gets involved earlier in the process, another can say "they knew things we didn't know", as noted by an interviewee. Therefore, if certain contractor is perceived by the competition as influencing in a way that brings unfair advantages, that situation can be contested, and the accused contractor prevented from bidding.

The most common way for contractors to influence early in the development of Public Building Projects is thru Partnering Contracts/Collaboration or contracts with only functional/performance requirements. Some believe that the involvement of consultants in the early stages of developing the design consequently results in more requirements than needed, maybe to make themselves more useful and 'required' during the early stages (instead of Contractors). As quoted by an interviewee, "with partnering, the construction companies took over a lot of things that consultants did. So, the consultants had to find a way to make money", further confirmed by another interviewee stating, "instead of using consultants and having a large consultant team, introducing drawings and instructions that only can be used for, like, 60% when the contractor enters the project, then I think it's more a net value for the money to have a contractor early in the in the process".

That situation is problematic, especially since, according to most contractor representatives that were interviewed, many times the Consultants are not experienced enough with construction to produce the most

Buildable solutions. Furthermore, some mentioned that client's experience might sometimes lead to the clients believing they have the knowledge required to develop tender briefings themselves and therefore do not need to involve contractors in the early stages. Hence, most believe that clients would be able to produce a better tender briefing if they involved Contractors earlier in the process, instead of defining their solutions with consultants.

Most interviewed contractors aspire for partnering, and most believe the client also gets the best value for the money. But a few mentioned that depending on the client (and consultant), they sometimes bring in too high expectations, and consequently, the budget to build it might end up greater than anticipated. In one interviewee's words, "clients dream too big, and so we eventually have to say no". Regarding that, contractor representatives mentioned that both the contractor and the client must be aware of the collaboration and the role that they have in such collaborative approaches. It is believed by some, that consultants end up allowing that 'bid dream' to happen, as they do not cap it early on. However, interest in partnering has varied over time (in waves), depending on market conditions, competition, client's expertise/confidence to run the project development by themselves or not, and past experiences with that. One mentioned that smaller municipalities followed the big municipalities approach to adapt partnering some years ago, but nowadays the big municipalities (e.g., Malmö and Gothenburg) are back at prioritizing regular design and build contracts (w/ fixed price), developing more projects with in-house construction experts, especially the kinds of projects that have been previously experienced by them and they feel confident to develop. But the Stockholm region, Örebro, and smaller municipalities, seems to still be a lot into partnering. Some interviewees also discussed that one of the reasons for decreased interest in partnering in the past few years is the higher competition due to the increased number of contractors, meaning that the more contractors there are on the market, the more potential to lower the price through more strict procurement. Contrary to that, some years ago when the market counted with fewer contractors – and with less strict public procurement regulations (LOU) – the public client could choose a company to develop and build their projects in closer collaboration. In other words, building procurement was more arbitrary.

Further, when asked what typologies, or characteristics of clients, that more commonly employ Partnering, respondents claimed it cannot be generalized this way. However, many mentioned that, for complex projects (one mentioned renovations with lots of uncertainties, another cited hospital, or 'bath house'), procuring with Partnering is pretty much the only way to go. Some mentioned that simpler Projects might be more expensive with Partnering, although a few disagreed with that, mentioning that Partnering can bring the cheaper solution for the Client needs, depending on the competence of the involved actors. It is, hence, a mean for many ends.

4.2.2 Theme II: Tender documents, Client requirements and the Bidding process

There are many ways of procuring with partnering. For instance, one can have partnering in some specific stages only, or in a part of the contract that is more complex. Also, more, or less collaboration can be applied. So, as of interviewees clarification, partnering is way more a 'shades of grey' situation than that 'black and white' (with or without Partnering), that most people believe it to be.

Further, most interviewees believe that the bureaucratic part of analyzing documents is inefficient and complex. However, it is also perceived as part of the process, as one mentioned, "construction is a complex business". Also, they do not think that this is very costly, although it does not sound convincing, since one mentioned "we just send all those documents to our legal department to analyze".

Moreover, Skåne, Stockholm, and Örebro, mentioned they receive models when they ask the clients for it. Gothenburg region and Halland (West), mentioned that models are either unusual or “never experienced that.” One interviewee - that is used to work in a small municipality - stressed “I usually receive a DVD”.

One resource-consuming part of tendering is conceiving a competitive proposal. For that, according to contractors, there is a need to count with different specialists and ‘*ping-pong’* a solution that is optimal for all the disciplines and attend to the client requirements with competitive cost. All that work with 6-7 specialists ‘*ping-ponging’* changes in design, is probably the most expensive part of conceiving a bid. Also, a couple mentioned that preparing the bills of quantities (BOQ) is expensive, with all the materials, parts, and labors itemized to enable the Contractor to price the work for the bidding. As mentioned by some interviewees, this is greatly simplified if they send a model, since there is obviously a lot of information already in it. But that is often not the case. Some mentioned that they can receive it if they ask the right people in the clients organization, but some others argued that is not their case, even when they ask for it.

The level of detail of requirements, of drawings and of stage of development, varies considerably. According to interviewees, it can differ from being barely detailed to being too detailed. Yet, most perceive it is better to receive a tender that is less detailed, allowing the contractor to bring his expertise and competitive advantage to win the bid. “That is what we do best.”

On the other hand, when clients send out the tender requirements and design less developed, there is, hence, a need for creating a proposal from *scratch*. This is more costly since the contractor needs to bring in many specialists from different areas to develop it. A reflection is that there is a lot of waste in that process, especially if we think of all the contractors developing costly proposals and only one winning. As a result, all other contractors will be putting their resource consuming work to waste.

Furthermore, most interviewees believe the tendering process is fair, although complex. It appears that they are not so worried about the process, since they feel that is what they are proficient at. But one way of seeing this, is that the way business as usual is done in tendering can be seen as a protection for the bigger contractors, as they learned to explore those bureaucratic gaps and the heavy work of conceiving proposals into opportunities. Smaller contractors cannot finance that costly and complex process, especially with the risk of not getting the job, so it results in less competition. In line with that, a few mentioned that the controversial material from tender documents are opportunities to produce a competitive advantage in proposals. Making use of their expertise. they may interpret what the client is in fact considering – or what will in fact happen as a consequence - and therefore, make use of that gap as competitive advantage.

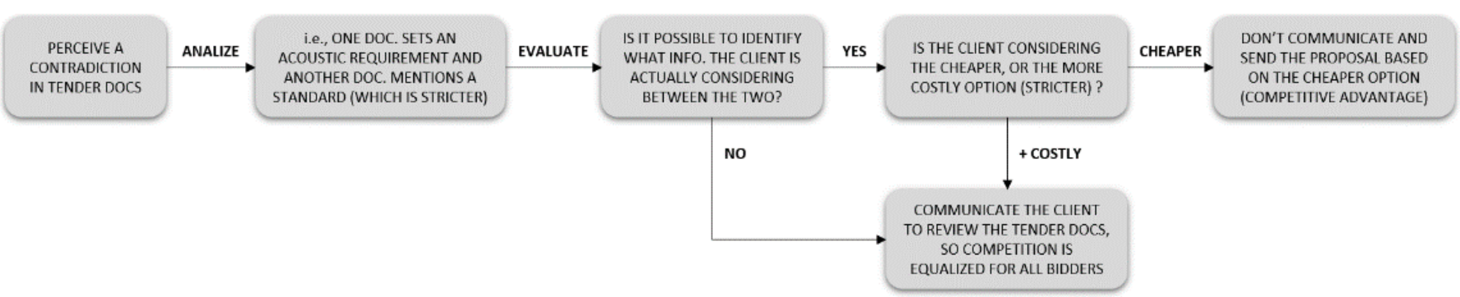


Figure 4.1: Informal process-flow of handling Tender contradictory information, as perceived by authors

In regard to these controversies, some municipalities - in interviewees opinion, particularly the small ones - often add what has been labelled in the industry as '*special requirements*' (explained in section 3.3.4) on top of ABT06. As revealed in the interviews, most contractors find it inefficient as ABT06 was developed by the industry to cover for that. They believe the client, and often their consultants, add more requirements on top, without really acknowledging why. Many of those 'special requirements' are not even used during the construction process, but they pose as a risk for the contractor, as depending on who controls it (which can eventually change along the project), might be required in the end, compromising the delivery. Matter of fact, there are diverse orientations on the Public Procurement Agency website, for Municipalities to avoid that practice, although as of contractors point of view that seems to be still a reality.

4.2.3 Theme III: Bidding process, knowledge transfer and sustainability

Business managers experienced with smaller municipalities mentioned that they do not really get to choose much what tender to bid on since the market is smaller, and therefore, they go for all that fit the profile (minimum net-value). Some contractors working in bigger municipalities mentioned that they used to go only for Partnering Projects, but since they got a little less now, they also started going for ABT06. Others are trying to create long-term relationships with clients, especially those in bigger municipalities, and in that way get the advantage to become more competitive than other contractors. Most of the interviewees agree that they would rather go for a tender with less requirements than one with more since it gives them more flexibility and freedom to use the technical solutions that are proven to be effective and increase the possibility to be innovative. Another point that some of the interviewees mentioned is that they have a type of criteria where they take into consideration who the client is if they have worked with that client before and how the collaboration has been during previous projects.

Regarding production data, most mentioned that it is hard to compare and that what is used today is more general data, such as cost/m2, etc. All agreed that it is hard to compare different projects since "all projects are unique" and even the general data in monetary terms that is available might be inaccurate. However, one idea that was discussed for production data is to compare parts of the building that are comparable.

Almost all interviewees agree that clients are getting more aware of sustainability, especially in terms of economically driven solutions, such as energy-efficient facade solutions, window frames, etc., that will provide return on investment. Also, LCA, as it is becoming a legal requirement soon, was also mentioned by some of them. Regarding responsibility for embodied carbon, some agreed that both the contractor and the client should take the leading role, and some even included the suppliers, while others are expecting the clients and consultants to set those requirements. Furthermore, some interviewees mentioned they leave *side-offers* to the client, when possible, to provide what they believe to be more valuable and sustainable solutions. These kinds of solutions are claimed to be more innovative and often "greener," which naturally, in some cases might end up more expensive. However, most contractors affirmed to be hopeless when it comes to proposing changes to public client tenders, since the perception is that they hardly will accept changes due to regulations restrictions. Also, the traditional approach to procurement is deeply based on lower price bids. hence often economic driven. Contractors believe that clients are also afraid to accept suggestions and miss to keep it in the preset budget. Therefore, as of today, the chances that these changes are going to be accepted by the client are low, as discussed by the interviewees. Time constraints are also mentioned by interviewees, stating that developing side-offers is resource-consuming and not conceivable in such a short period of time to allow clients to evaluate it and officially approve it. As a result, most contractors claim to formulate the most competitive proposal, considering the given client requirements.

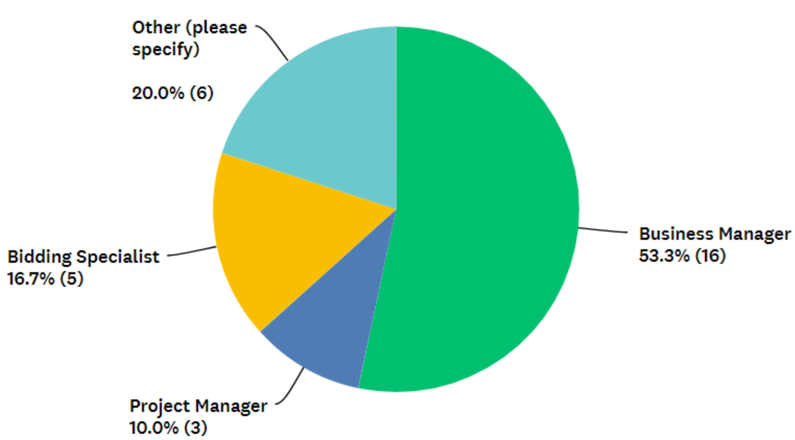
4.3 Survey (Quantitative approach)

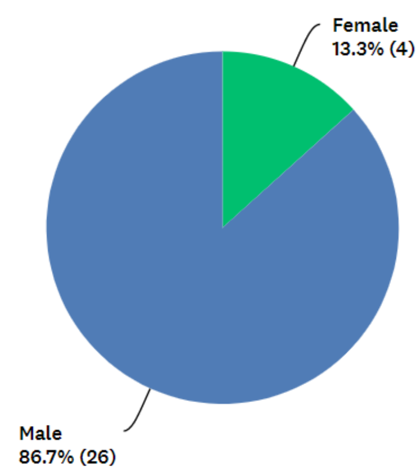
In this section, data collected from the survey is presented. As expected from the 'exploratory' approach, the scope of this quantitative instrument is driven by the learnings acquired from the previous qualitative investigations. As such, the survey questions do not necessarily reproduce the exact subjects and structure. On the contrary, it is highly expected that the survey questions suffer several adaptions based on the findings from the interviews as these come to show the more interesting issues to be further investigated.

In line with that, the first part of questions that are tackled in the interviews, which dive into 'early involvement of contractors' (EIC) and 'partnering' (named 'Theme I', in page x), provided enough data to be discontinued. That decision is taken because interviewees are quite unanimous in their answers. Also, it is sufficiently clarified in the interview answers that EIC and partnering are not scalable solutions that contractors can count on to achieve the ambitious desired goals in the building sector. Hence, there was simply no reason to continue asking about this kind of matter on the survey. At the same time, as interviews revealed the challenges to be greater in certain specific conditions - such as public building tenders on regular Design and Build (DB) - the survey, hence, focused on contractor representatives that are used to work with public clients. As of consequence, the survey tackles the 'Theme II' and 'Theme III' in conformity with the interviews and adds in other new subjects. Meanwhile, as the sample narrowed down to individuals who could answer in the perspective of public tenders (without partnering), it has also - as a demand for more quantity - adapted to incorporate more respondents in less senior positions. As such, the survey counted with business managers, project managers, bidding specialists, estimators, and other diverse experts. As previously explained in the method chapter, that change on the sample was perceived as necessary mainly because contractor business managers are quite scarce and often too busy to reach and answer. Another reason for that change is based on the understanding that many questions addressed in the survey are probably too specific and operational to be answered by business managers that are often more involved in strategic duties. Based on that new enlarged sample, 105 contractor representatives were contacted and 30 completed the survey questionnaire, resulting on a tax of response of 28.57%.

4.3.1 Respondents Profile

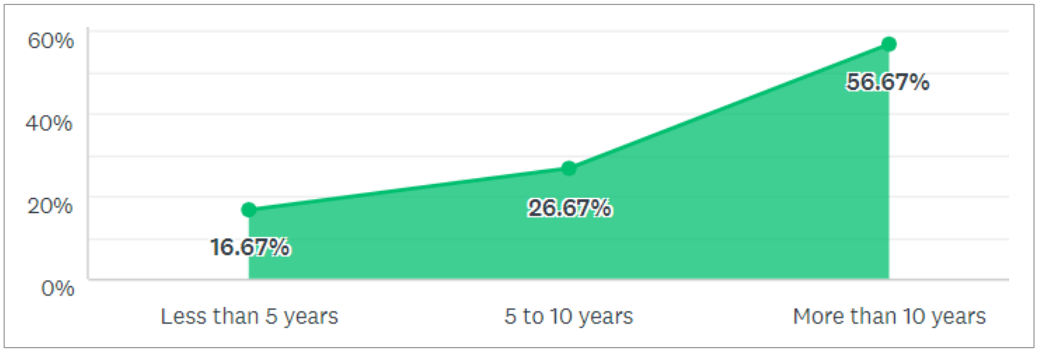
As illustrated on the following charts, around half the respondents are business managers, while the rest is divided between the previously mentioned positions. That higher amount of business managers is justified on the fact that these individuals were already in closer contact due to the undertaken interviews.





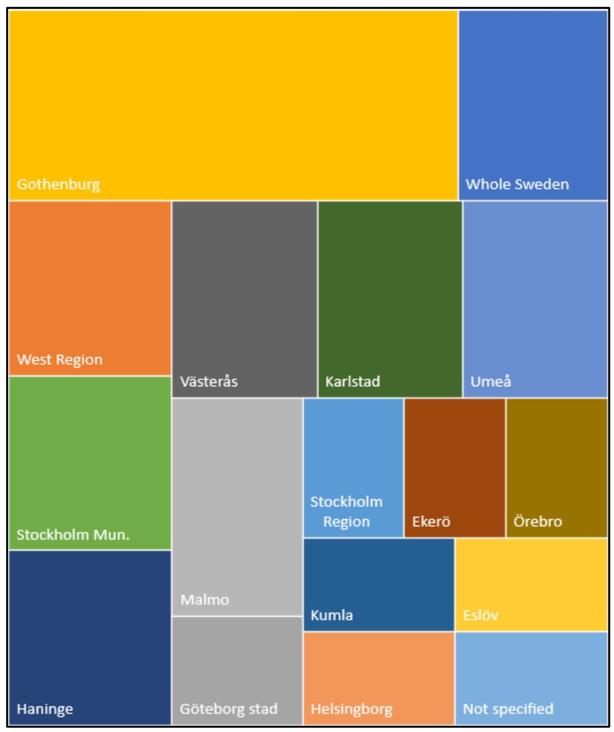
Another interesting data demonstrates the quite low proportion of females (13.3%) that attended the survey. Although off-topic, that information comes to expose how unequal is the gender situation in Engineering roles, especially in top management positions.

Furthermore, the average experience of the ones who took the survey is shown in the following graphic, revealing that more than half of the respondents have more than 10 years of expertise with buildings public tendering.



Lastly, in regard to respondents geographic locations, the distribution goes as following:

Location	%	Region	%
Whole Sweden	7%	All	7%
West Region	7%	West	
Gothenburg (state)	3%	West	30%
Gothenburg	20%	West	
Stockholm (state)	3%	East	
Stockholm	7%	East	
Haninge	7%	East	
Ekerö	3%	East	33%
Västerås	7%	East	
Örebro	3%	East	
Kumla	3%	East	
Karlstad	7%	Central	7%
Umeå	7%	Northeast	7%
Helsingborg	3%	South	
Malmo	7%	South	13%
Eslöv	3%	South	
Not Specified	3%	NA	3%

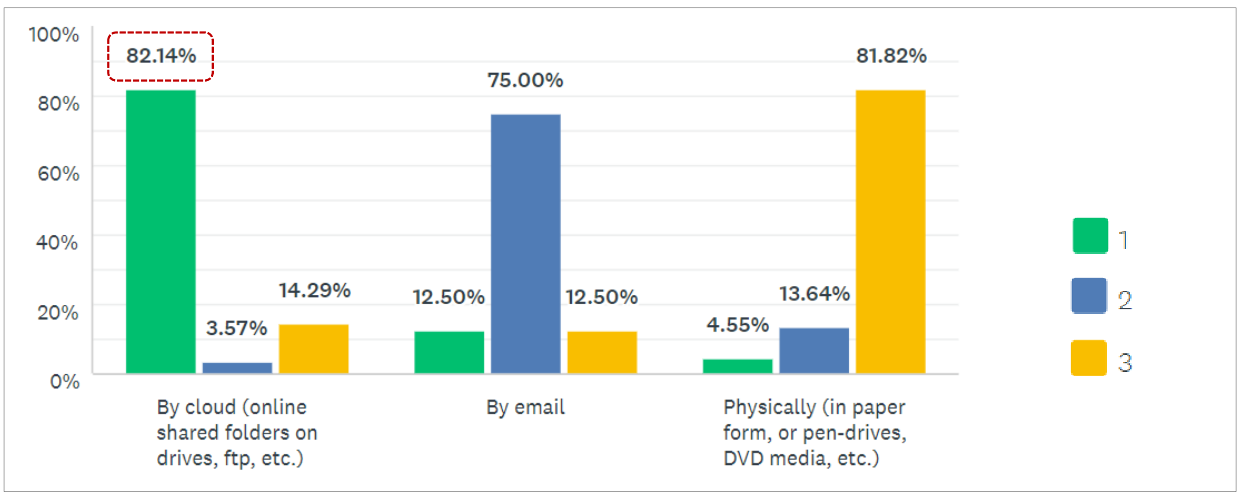


It can be observed that most respondents (66%) are located in East and West Sweden, based mainly on Gothenburg and Stockholm regions. As the most populous region of Sweden, Stockholm - added by Örebro surroundings - comprise the East side and thus represents a big share of respondents due to the likely higher quantity of personnel allocated in this big Swedish market. Therefore, the East region represents the majority of respondents, with 33%. Following that same logic, Gothenburg, as the second-largest population in Sweden, has also been quite well represented. Another relevant reason for the big share of survey respondents located in the West region is justified by the close relationship and noticeably strong network between Chalmers university and industry representatives in the West. That, as a consequence, created the conditions for these individuals to be more easily found and contacted by the authors. Followed by these two, the South Region, comprising the third more populous city in Sweden (*Malmö*), also embodies a considerable share of respondents, with 13%. Lastly, 21% of respondents left are divided between *Whole Sweden*, *Karlstad*, *Umeå*, and *Not Specified*.

4.3.2 Theme II: Tender Documents, Client Requirements & Drawings

In this first theme of the survey (named as *theme II* to associate with the structure of the interview), the questions that are undertaken address how digitalized the information is, how efficient is the flow of data between clients and contractors, and how impactful are different types of client requirements.

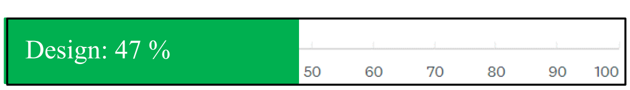
With that in mind, the first practical question requested contractor representatives to order from 1 to 3 the frequency of "how are Tender documents handled by Public Clients / Consultants (in ABT06 contracts)."



As observed in the resulting chart, more than 80% have access to tender documents through some sort of cloud service. Only a small portion of contractors still receive documents through email or physical form.

Furthermore, it has been asked "*how digitalized are Tender requirements handled to you by Public Clients / Consultants?*" And to clarify that query, it has been stated that answering with '0%' would mean they receive it in a *Physical Paper form.* The middle of the bar - or 50% - means *raster PDFs.* And lastly, answering with a full bar - or 100% - means that the requirements are delivered in some kind of *open-format file*. As a result, in a rating system from 1-100%, the requirements achieved 67%.

Followed that same logic, it has been asked "*how is Design handled to you by Public Clients / Consultants in 'Totalentreprenad' (ABT06)*?" And it was indicated that 0% means *blueprints on PDFs*, 50% relates to *CAD files*, and as 100% to *BIM models*. As a result, the Design query accomplished 47%.

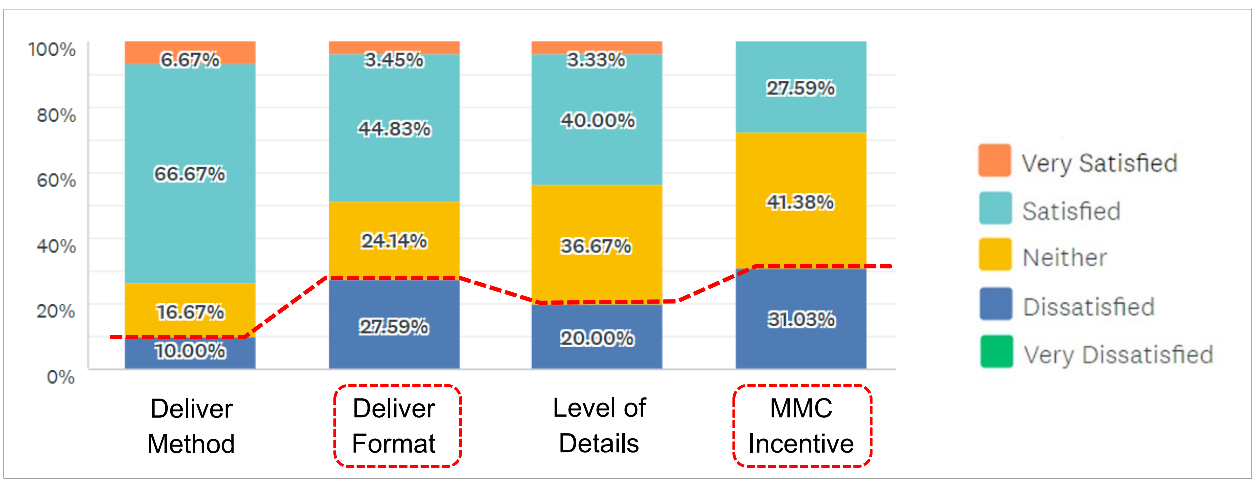


Continuing through the survey, it has been asked "*How resource-efficient do you think the Tendering Process is, in regard to information-flow?*" and the collected data indicates that in perspective of most contractors, the *information-flow* during tenders is neither efficient nor inefficient, with the resulting rating of 5.2 out of 10, as illustrated in the following bar.

	TOTALLY INEFFICIENT AND WASTEFUL	(NO LABEL)	(NO LABEL)	(NO LABEL)	(NO LABEL)	(NO LABEL) 5.2	(NO LABEL)	(NO LABEL)	(NO LABEL)	HIGHLY EFFICIENT	TOTAL
☆	0.00% 0	3.33% 1	13.33% 4	23.33% 7	16.67% 5	16.67% 5	13.33% 4	13.33% 4	0.00% 0	0.00% 0	30

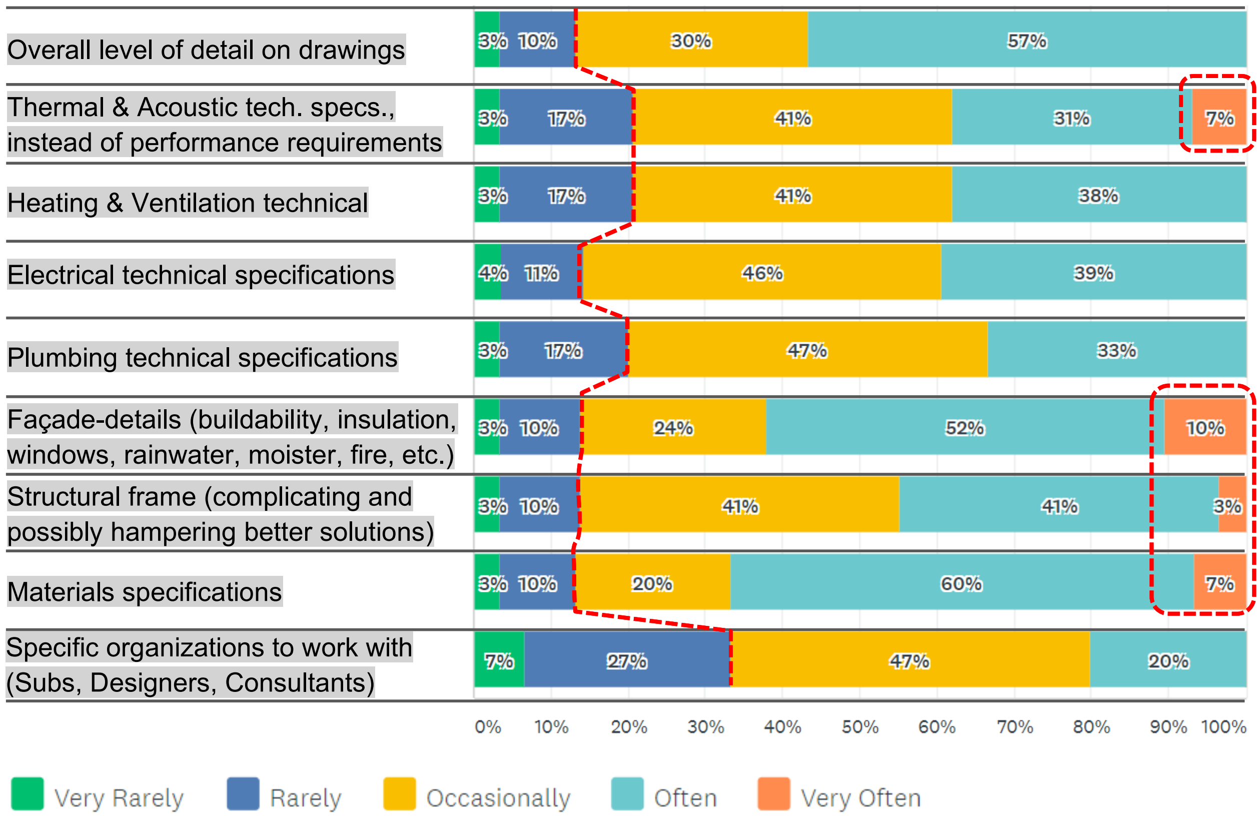
Subsequently, it is asked "*What is your level of satisfaction with early stages Public Tendering processes when it comes to...*", and so, the four following issues are introduced: "*How are delivered the Tender documents*", "*The format of such delivered information*", "*the Level of Detail of requirements and drawings*", and lastly, "*Client incentives for Contractors to use Modern Methods of Construction (MMC)*".

As the following chart indicates, all of the four tackled issues perform quite well in terms of contractors 'Satisfaction'. The *Delivery Method* subject, to mention one, has returned with only 10% of respondents somewhat *Dissatisfied.* This means that, in turn, a quite high share (90%) of contractors feels to be at least *Neither satisfied nor dissatisfied* (16.67%), *Satisfied* (66.67%), or *Very Satisfied* (6.67%), with the way the tender documents are delivered. In regard to that, the two subjects that perform a little worst in terms of satisfaction are "*the format of such delivered information",* with almost 30% *dissatisfied*, and "*Client incentives for Contractors to use Modern Methods of Construction (MMC)*", with 31% feeling *dissatisfied*. In line with that, not even one respondent claimed to feel *very dissatisfied* in any of the introduced subjects.



As observed in the chart (and similarly used in some of other graphs further ahead), the red dashed line crossing the chart serves to emphasize the *dissatisfaction* line.

Subsequentially, it has been asked how often in ABT06 Tenders, *"the following subjects considerably impact Buildability and hands-ties the Contractor?"*



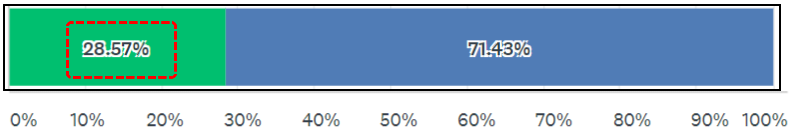
As revealed in the chart, all of the introduced subjects often "*considerably impact Buildability*" and the contractors flexibility. That is clear when observing that the sum of *very rarely* or *rarely* answers comprises, in most cases, a very short percentage of the answers, varying between 13% and 20% (as highlighted by the red dashed line). Consequently, around 80% believe these subjects considerably impacts buildability. Lastly, in four of these (*thermal & acoustic*, *façade*, *structural frame*, and *materials*), it has been claimed by at least one respondent that it *very often* considerably impacts buildability.

4.3.3 Theme III: Bidding Processes & Knowledge Transfer

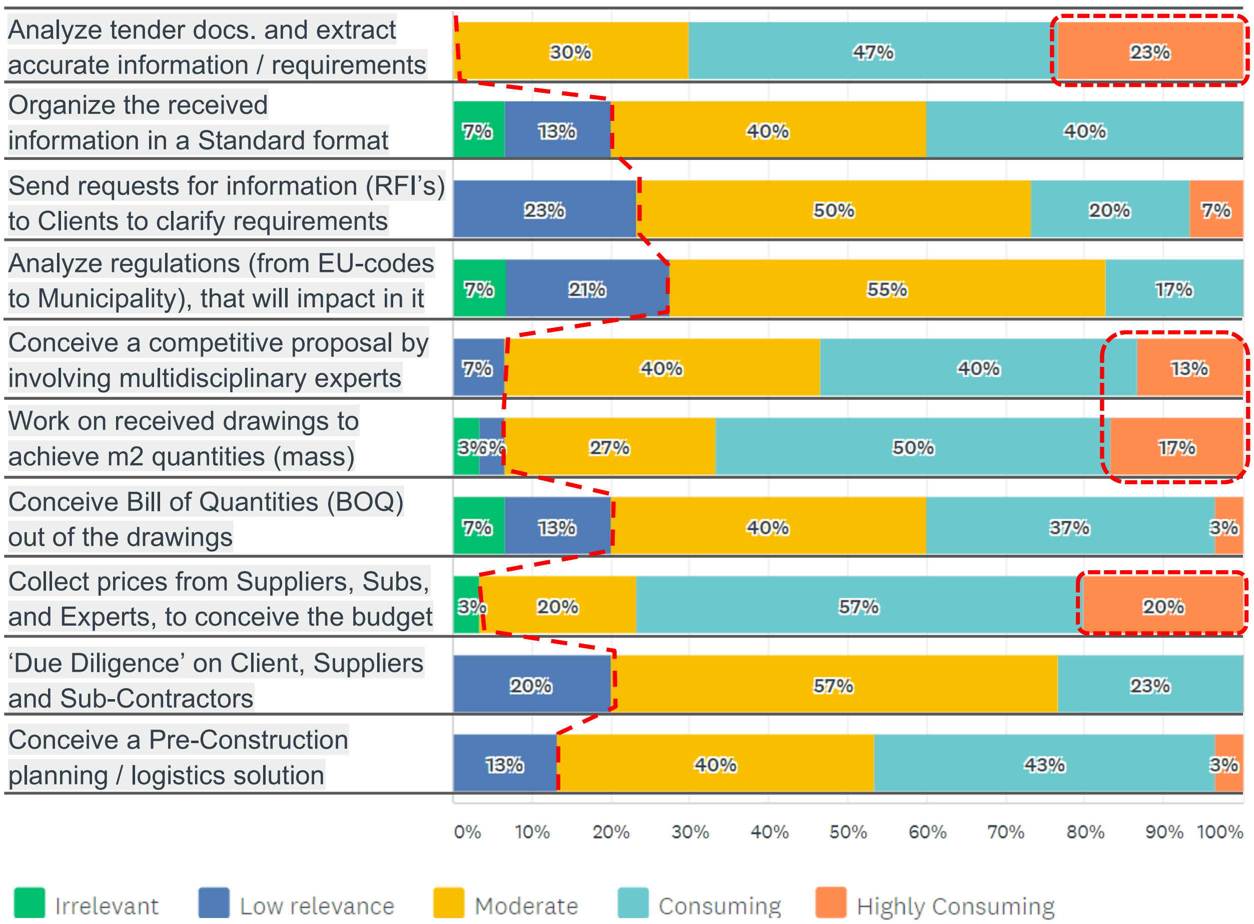
Theme III of the survey has tackled subjects related to contractors bidding processes. Accordingly, a few questions attempted to clarify the highest perceived difficulties, inefficiencies, and opportunities for improvement in contractors tendering procedures.

With that goal, the first question of this section has asked if, "*when approaching a Public 'TotalEntrepenad' (ABT06) building tender,*" the contractor respondent more often "*critically analyze 'Client requirements' & 'Concept Design', and propose side-offers with changes to facilitate Buildability / Sustainability*", or "*avoid spending time and resources proposing changes on Tender Briefing, and instead, focus resources on conceiving the most competitive proposal on top of what the Client already defined as requirements?*"

And as illustrated in the following graph, only 28.57% of the respondents more often propose side-offers. In turn, a vast majority of 71.43% focus resources on conceiving a competitive bid based on the clients' requirements at hand.

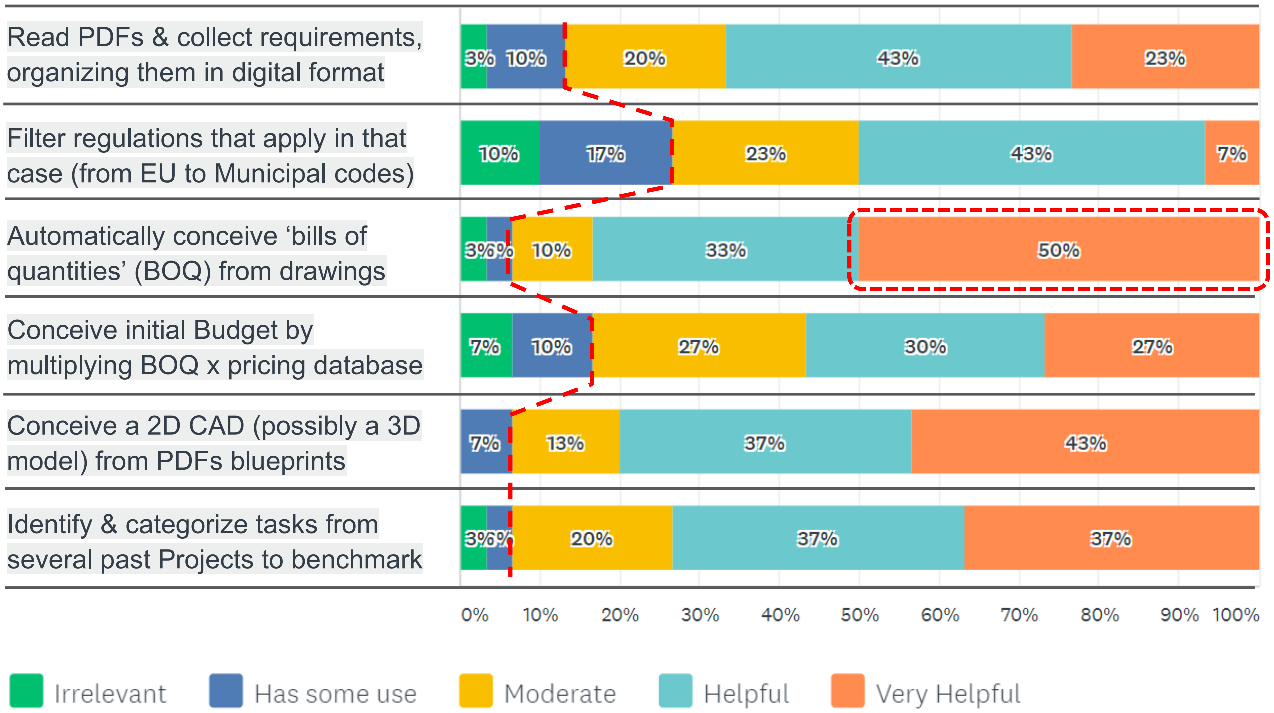


Further, it has been asked "*how resource-consuming*" are a few given tasks "*when preparing bids for ABT06 building Tenders?*" And as observed in the subsequent chart, all of the introduced subjects are responsible for considerable consuming tasks.



Although all subjects are notable relevant, a few can be highlighted. The first one, labeled as "*analyze tender documents and extract accurate information / requirements*", for instance, has returned with none of the answers on *irrelevant* or *low relevance*. In turn, 30% said it is *moderately* relevant, 47% think it is *consuming*, and 23% feels that this kind of task is *highly consuming*. In other words, it is a quite relevant subject. Other noteworthy tasks to be emphasized due to the remarkable results are "*conceive a competitive proposal by involving multidisciplinary experts*", "*work on received drawings to achieve m2 quantities (mass)*", and "*collect prices from Suppliers, Subs, and Experts, to conceive the budget*."

Continuing through the survey, it has been asked "*what tasks would be helpful if automatized?*" and a list of suggestions were presented, as illustrated in the following chart.



As it can be observed by contractors' answers, in their opinions, it would be considerably advantageous if any of the suggested tasks could be automatized. However, apparently the most promising is "*automatically conceive bills of quantities (BOQ) from drawings*" with the highest share of *very helpful* results. Other than that, "*read PDFs and collect requirements, organizing them in digital format*", presented only 13% of answers rating it as *irrelevant* or considering it *has some use,* whilst 87% deeming it to be at least *moderately* helpful. Furthermore, "*conceive a 2D CAD (possibly a 3D model) from PDFs blueprints*" and "*identify & categorize tasks from several past Projects to benchmark*" are also considered highly helpful, as its outcome demonstrated more than 90% rated these tasks between *moderate*, *helpful,* and *very helpful*.

Furthermore, the survey inquired respondents for their contributions on "*how to improve the Tendering Process to leverage modern methods of Construction*." Differently than previous questions, this one approached the survey respondents without predetermined multiple choices, intentionally leaving more freedom for diverse opinions. As a result, one suggested to "*continue with partnering and early-contractor-involvement*" and "*collaborative contracts*". Further, one recommended to allow "*a larger possibility to choose methods/solutions by ourselves*" (Contractors flexibility), or even to "*follow up and evaluate specified requirements*" provided by Clients. Another respondent advocated for the delivery of "*3D models by the customer*", certainly as means to facilitate the contractor's work to calculate the bid.

In the last part, the survey approached questions related to knowledge transfer. It started by asking contractors "*what kind of 'lesson learned' knowledge do you feel being more relevant to have as a decision-maker on new bidding processes?*" And asked them to order the given options from 1 to 5:

A) Statistical data showing the tasks with the most impactful Cost-Overruns and the causes for that. For example, a 'lesson-learned' could be that 'ceiling tasks' often end up more expensive than budget by X% due to damage on the fragile material poorly stocked on-site (unforeseen waste).

B) Statistical data showing the tasks with the most impactful Delays, and the causes for that. For example, one 'lesson-learned' could hypothetically be that 'excavation tasks' frequently delays from the planned schedule by X% when it is executed during rainy seasons.

C) Statistical data showing accidents and specific causes.

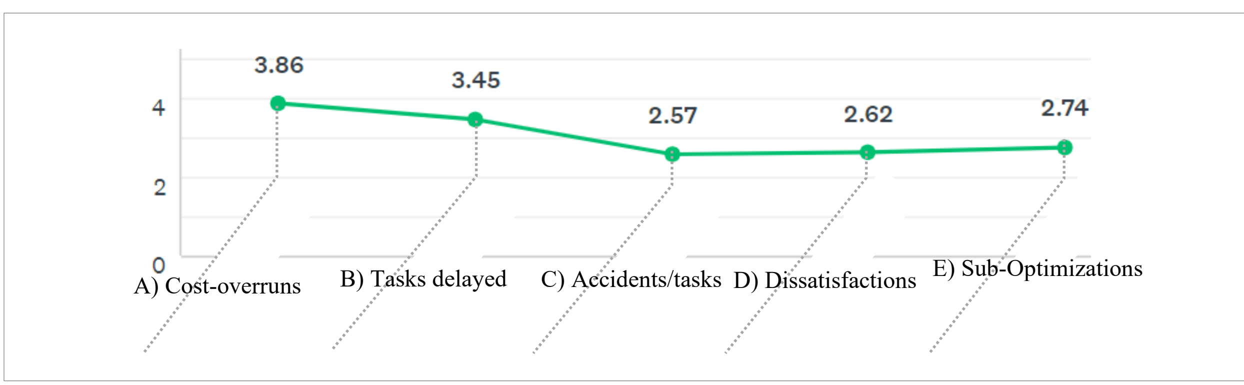
D) Statistical data showing Client dissatisfactions and the causes for that.

E) Statistical data showing Contractor's (Project or Site Manager) perceived-sub optimizations and the causes for that.

The outcome is presented in the subsequent table, showing the answers in detail. This kind of visualization is interesting to better perceive respondents standpoint. Two interesting findings worth underlining is that a high share of 42.8% respondents believe that *Cost-Overruns* is the most important data (ordered it as '*1*'), whilst that same amount indicated that *Accidents* is the least important ('*5*') between the suggested subjects.

Lessons Learned	1	2	3	4	5	TOTAL	SCORE
Cost-Overruns and the causes	42.86% 9	23.81% 5	19.05% 4	4.76% 1	9.52% 2	21	3.86
Delays and the causes	18.18% 4	31.82% 7	27.27% 6	22.73% 5	0.00% 0	22	3.45
Accidents and specific causes	23.81% 5	14.29% 3	0.00% 0	19.05% 4	42.86% 9	21	2.57
Client dissatisfactions and the causes	4.76% 1	28.57% 6	14.29% 3	28.57% 6	23.81% 5	21	2.62
Contractor's perceived-sub optimizations and causes	13.04% 3	8.70% 2	39.13% 9	17.39% 4	21.74% 5	23	2.74

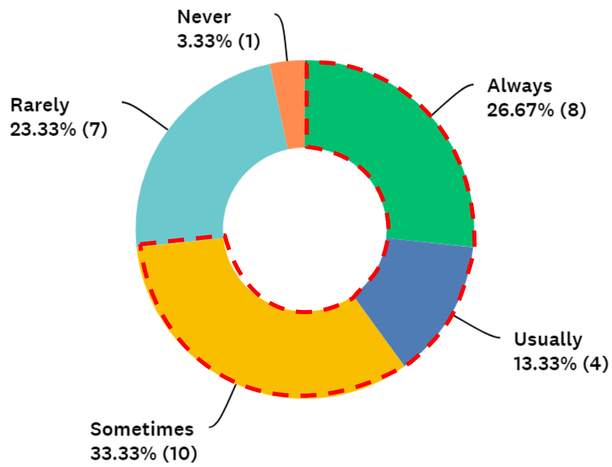
The importance given to each subject can be better illustrated in the subsequent graph, considering only the consolidated scores of the presented options. In this, it can be better observed that lessons learned related to *Cost overruns*, with a 3.86 score, is the most relevant subject in the perspective of Swedish contractors.



Furthermore, in regard to the previously introduced types of data (i.e., cost-overruns, delays, accidents, etc.), it was asked if respondents had any other kind of Production-data to openly suggest. However, only one person made use of this field to suggest "*a way to state reference prices for different projects and different parts of the project*", "*to find relevant way of comparing between projects*."

Continuing throughout the survey, it was asked "*how frequently*" the contractor representatives "*manage to apply 'lessons learned' on new bidding processes, specifically by making use of some sort of tool with a 'Production-Database'? (Other than cost/sqm and the usual general data)*"

As a result, it can be observed in the donut chart on the right, that the total share of answers that *sometimes*, *usually*, or *always* manage to make use of production-data, accounts for more than 70%, as highlighted with a red dashed line on the graph.



Subsequent to that, in an effort to better contextualize the previous answers, the last question of the survey introduced the following affirmations and invited respondents to mark the ones they agreed with.

ANSWER CHOICES	RESPONSES	
I feel the sources and premises of Production-data are trustworthy and standardized enough to benchmark	23.08%	6
My current organization's Database / 'Knowledge-Transfer digital tool' is easy-to-use and user friendly	26.92%	7
My current organization's 'Knowledge-Transfer digital tool' provides not just costs per-square-meter and other usual general data, but also more specific tasks-related data (by showing certain conditions and the causes for it to occur)	11.54%	3
Time-constraints heavily hinder 'Production-Data' usage possibility during Tendering	15.38%	4
I get more specific 'lessons-learned' information by talking to other people (experienced with similar Projects)	69.23%	18
Total Respondents: 26		

As observed by the responses (on the right side of the table), a quite low share of 23% "*feel the sources and premises of Production-data are trustworthy and standardized enough to benchmark*". Further, less than 27% believe their organization's database is *easy to use*. And an even lower percentage of 11.54% counts with a knowledge-transfer tool that provides *more specific tasks-related data* (instead of the usual general data, like cost per square meter). Moreover, only 15.38% agreed that "*time-constraints heavily hinder 'production-data' usage possibility during Tendering*", and almost 70% "*get more specific lessons-learned information by talking to other people (experienced with similar Projects)*".

With that, the survey analysis is concluded.

4.4 Studied Organization Overview

4.4.1 Purpose

According to NCC's webpage, "every generation has the **responsibility** of building and maintaining society with its infrastructure," leaving it in "a better shape for **generations to come**." Thus, the company believe their "**expertise and knowledge**, can add to this positive impact," delivering more "**sustainable solutions**."

Fittingly, NCC's purpose is to continuously challenge themselves and their customers "throughout the construction process for the **best possible solution**," taking the customer "to a **positive end-result for all stakeholders**."

4.4.2 Values

NCC values, collected from the company's webpage, are:

- "Challenge ourselves and each other to constantly improve and outperform our targets"
- "Work actively to ensure effective collaboration internally, in and between units, and together with our customers"
- "Data-informed decisions, communicate them clearly and always act on what's decided
- "Take responsibility for our actions and use of resources. We mitigate risk and act with integrity to ensure safe, high-quality and sustainable operations"

4.4.3 Environmental Responsibility

Further, as part of a *Code of Conduct*, the *Environmental Responsibility* mentions the pursue of "a long-term sustainability strategy encompassing **environmental, social and economic aspects of sustainability**. Innovative thinking and **innovations that contribute to sustainable** development are encouraged in dialog with customers and other stakeholders." Further, it is claimed that "responsibility for the environment means always complying with **environmental legislation** in the markets where we are active, as well as seeking to develop more energy-efficient, climate-adapted and **resource-efficient products and services** throughout the product lifecycle," and "NCC collaborates to achieve the goals of the Fossil-Free Sweden initiative," meaning to be compromised with carbon neutrality by 2045. "Before and during projects" NCC "work with our customers, suppliers and partners **to develop superior sustainable solutions,**" whereas also "being able to offer housing and infrastructure that **everyone can afford.**"

Suitably, according to information on NCCs' webpage, inhouse and third-party audits ensure **compliance with the UN's Global Compact**. With that, the company has been reporting to UN's Global Compact since 2010 and annually submits a description of the practical actions the company is pursuing.

On a more practical level, as informed during a supervision meeting, the company already provides Life Cycle Assessments (LCA) for all buildings being built by NCC, even if it is not required by the client. This, goes in harmony with their

4.4.3 Digitalization

For NCC, "digitalization is about the ability to use and create **value from the information**" its generated and accessed by the company. It is supported a "long-term approach to digitization", focused on "creating a future-proof platform to facilitate a **seamless flow of information**". There is an ongoing effort "to digitize and integrate" NCC's processes and "develop services and collaborations with external parties".

Digitalization, according to NCC's page, can also improve "the ability to **anticipate risks**, for example economic, quality, sustainability, and health & safety risks". Furthermore, it helps achieving "calculation opportunities to optimize design, cost, material consumption and transports, to mention some areas."

Moreover, digitalization often leads to "opportunities to improve internal **efficiency**, **meet regulatory requirements** and develop new products and services". Additionally, according to NCC's webpage, a common and standardized digital language, could bring about benefits along the value-chain, such as:

1. Lower costs and environmental impact for all parties in the value chain
2. Increased productivity with shorter construction processes
3. Control and monitoring of sustainability
4. Available lifecycle data

However, according to information collected during a supervision meeting, there is currently a challenge to benchmark different projects data, due to the uniqueness factor. In parts because of this, knowledge transfer solutions, are poorly addressed (particularly during tendering).

Lastly, as of information from the company's website, to support efficient management of the business, NCC "uses a process-oriented business system that meets the requirements of ISO 9001 (quality), ISO 14001 (environment) and OHSAS18001 / ISO 45001 (work environment). The ISO certificates ensure that NCC works continuously with continuous improvements to working methods, and tools".

4 Analysis

In this chapter, data collected from empirical research is compared with theory in an objective approach. It is demonstrated that most findings converge with papers explored in this thesis, although some empirical data show diverging perspectives. An interpretative analysis of these results is developed in chapter 6.

5.1 Theme I: Early Involvement of Contractor (EIC), Collaboration and Partnering

As presented in chapter 3.3.5, the DB procurement route - or '*totalentreprenad'* - was firstly envisioned aiming to grant contractors enough independence to idealize their own technical construction solutions, often perceived as superiorly efficient to attend the agreed project outcomes. However, it has been claimed by many Swedish contractors interviewees that technical 'prescriptive requirements' are often too detailed and overly present in regular DB tendering, and hence pose a considerable challenge for contractors flexibility. In regard to that, different sources reviewed in chapter 3.3.6 advocate that 'Clients' should rely more on the so-called 'performance requirements', to facilitate the realization of 'functional requirements' through innovative and possibly more efficient construction methods. However, interviewees also revealed that often when it comes to regular Design-and-Build, the possibilities for the contractor to be involved early by public clients are fairly limited due to the 'public procurement act' (LOU), which establishes legal parameters for fair competition, as discussed in chapter 3.3.2. As such, contractors claim that most of the time in public tenders, even if they send a side-offer to the client with allegedly more efficient solutions, the chances for the client to adopt them are slim. Partly because of that, it has been strongly argued by interviewees and academia (chapter 3.3.5), in favor of the collaborative 'Partnering' route, since in that, the contractor is officially involved in the earliest stages of project development (Figure 3.6). However, interview findings expose that many public Swedish clients have been reducing interest in partnering over the last few years. In contractors opinions, that comportment seems to be justified partly on macro-economic fluctuations over the years and a belief that a regular DB approach - grounded on a fixed price - offers clients less risk of losing control over costs and available budget. That seems to be particularly the case in less complex buildings, where enough technical knowledge for early project development is believed to exist in-house. As a result, employment of 'EIC' is perceived as unnecessary, as argued by both interviewees and literature (chapter 3.2.3). In fact, according to contractors, that sense of risk is exactly what leads Public Clients to every so often rely on overly described 'prescriptive requirements', inflated tender documents, and even 'special requirements' on top of standard agreements like the 'ABT06', producing by that the previously mentioned ambiguity and unwelcomed inflexibility. In agreement with this perspective, such inefficiencies have been recognized by Swedish authorities with the consideration that it "leaves limited room for innovations and variations in construction", and thus, several legal changes are presently taking shape by a committee "modernizing and simplifying regulations, promoting increased housing construction and increased competition, without compromising health, safety, quality of design, a good living environment and long-term sustainable construction", as revealed in chapter 3.3.6.

5.2 Theme II: Tender documents, Client requirements, and Contractors bidding process

While analyzing the tender documents, it has been noted that not all tender briefings are conceived in the 'AMA AF' standard framework (chapter 4.1, Table 4.2). Instead, these papers contain different numbers and structures, with requirements being addressed in different documents such as technical and framework descriptions (Table 4.1). That kind of disorder has also been mentioned by a few interviewees, emphasizing that the AMA format is an agreement developed in collaboration between industry representatives and Swedish authorities. This kind of concern is coherent with the data collected from the survey, exposing a satisfaction rate of 5.1 out of 10 in regard to public tenders 'information-flow'. Yet, as further revealed in the survey, contractors are surprisingly satisfied with the 'methods' of tender documents delivery and documents 'format', as well as the 'level of detail' of requirements, although they clearly consider highly 'resource-consuming' many tasks directly related to processing these documents. The work to "Analyze tender documents and extract the accurate information/client requirements", for instance, is considered by all survey respondents as at least 'moderately' consuming, while 68.9% consider it either 'consuming' or 'highly-consuming', as revealed in chapter 4.3. Additionally, respondents rated the level of digitalization of 'drawings' and 'requirements' in briefings as low as 45% and 67%, respectively, reinforcing the satisfaction contradiction. Such paradox can be justified based on data collected from interviews. In that, a few contractors visibly showed a high acceptance with the fact that "construction is a complex business", claiming "that is what we are good at". A reduced number of Contractors, however, showed in the interview a noticeable level of dissatisfaction. One in particular stressed the fact that money from taxes is not being well applied due to tendering inefficiencies.

Moreover, the analysis of the documents showed that only one out of 12 tenders require a life cycle assessment (LCA) for the building, besides the other three that naturally demand it due to the environmental certification requirement. As argued by Beemsterboer et al. (2020), the demand and knowledge for LCA for buildings are low, resulting in different challenges, such as data collection and time (Chapter 3.2.1). Such low demand for that fits interviewees perception that other than operational performance concerns - clearly economic driven - clients do not prioritize sustainability in requirements. It has been argued by interviewees, however, that clients' awareness of environmental concerns has been increasing, especially over the past couple of years. This 'growing awareness' can well be a result of the recent governmental efforts to change regulations. In this case, particularly the demand for building environmental declarations, which has been brought public in 2017 and comes to effect in January 2022.

Additionally, as showed in Appendix 1, the analysis of tender documents revealed the presence of diverse technical specifications in the form of both 'prescriptive' and 'performance requirements'. It has been accepted, however, to be impractical for the authors to evaluate how impactful these requirements are in regard to Buildability, especially due to time constraints. It well-served, however, to illuminate the types of subjects that are most often required. Also, it has proven especially relevant to shed light on the complexity of the process and the many opportunities for improvements. Still, for a more specific comprehension of the relative impact of these different requirements in Buildability, the survey with Contractors has uncovered some relevant data. 'Thermal & acoustic', 'facade details', 'structural frame' and 'materials specifications' - to mention a few - are visibly highly impactful, and when comparing to the analyzed documents, these requirements are largely present, with 'Acoustic requirements' appearing in 41.7% of the tenders; 'energy consumption' - which can possibly convey with 'façade' - in 58.3%; 'structural framing' in 41.7%; and lastly, 'materials' and 'components', in 58.3% and 66.7%, respectively. Yet, further studies questioning how limiting are the 'prescriptive requirements' present in it can be attended in a future occasion.

Moreover, as approached in chapter 3.1.3, different initiatives, most notably RIBA plan of work report (2020), suggests that environmental impact assessments need to be addressed not only in concept design, but instead, continuously measured along all stages of the Project until aftermarket, from 'RIBA stage X' to Y. That is evidently not the reality found in the collected empirical data since LCA, as just mentioned, is only required in one Project (other than the environmentally certified). On the other hand, the contractor organization in the study revealed in chapter 4.4 that LCA has already been implemented as an internal requisite in their organization, demanding it to be conceived in all their contracted building projects, even if the client does not require it. Furthermore, as revealed in chapter 3.1.3, authorities in Sweden are setting LCA as demand for all building permits, starting already by January 2022. Along with that initiative, progressive targets for embodied carbon reduction are set, starting with a 25% reduction by 2027 to carbon neutrality by 2045. However, RIBA, also supported by other authors (Beemsterboer et al., 2020; Karlsson et al., 2020), claims that LCA delivered in the early stages are challenging and not so accurate and need to be revised along with product development. Such argument is further supported by the curve of assessment accuracy in time, illustrated in figure 3.3 (*UK-GBC's, 2017)*, in chapter 3.1.3.

Another relevant topic regards criteria. While literature supports varied multi-criteria assessment methods to base decisions addressing a more complete view, the current reality of the industry reveals a totally distinct approach. Analysis of tender documents shows that assessment methods and tools are still in their infancy regarding applicability. Interview and survey show that contractors often use "informal talk", and the use of production data, is currently far from its potential, partially due to reasons exposed in the survey, such as lack of trust on the premises of standardization and the 'user-friendly' aspect of tools. Thus, reaching reliable data to inform the so-called 'multi-criteria decision-analysis' can be challenging.

Furthermore, the 'level of detail' present in analyzed tender briefings varies greatly, explaining why some tenders contained only two documents, while others 40 or more. Most interviewees further reinforced that the 'level of detail' often varies considerably depending on project complexity, procurement type, and client profile. That interview finding can, in parts, be justified on the profile of the interviewees, whose responsibilities are associated with the most diverse kinds of procurement dynamics, such as private clients and partnering. The decision to primarily listen to managers from all types of procurement dynamics goes in line with the first phase of the research methodology, which aims to be 'exploratory'. However, the results naturally varied a lot depending on these different tendering dynamics, with an expected lower level of development, and consequently details, on private contracting or partnering. However, as revealed in the survey data in chapter 4.3.1, when it comes to 'level of detail' only 20.69% of the respondents are 'dissatisfied' with how Public regular DB tender documents are received, while almost 80% are at least 'ok' (neither) with it. That perceived 'satisfaction' obtained from the survey may be explained by insight from one of the interviewees, who argued that while a tender with a lower 'level of detail' is preferred by Contractors due to higher flexibility (Buildability), it is also more costly as it demands a considerably long and 'resource-consuming' work (also in line with the survey), involving experts from various disciplines to formulate a competitive proposal that might well be lost - and thus, gone to waste.

In summary, the result from the survey shows that 'information-flow' can be highly improved, even though contractors at large extent see the complexities and resource-consuming tasks as part of the business.

5.3 Theme III: Contractors bidding strategy

As presented in chapter 4.3.2, the most resource-consuming task is ‘Analyzing tender documents’, where none of the respondents found the task as “irrelevant” or with “low relevance”. All tasks included in this question are at least “moderate” resource consuming, meaning that the bidding process is seen as resource consuming. However, the interviewees did not seem to see many issues with this task, as already stated in chapter 5.2, although they agreed that time constraints limit the process of bidding since clients often publish the tenders too late and give a short deadline for the bids. This reasoning may explain why only 28.6% of the respondents in the survey leave side-offers, and 71.4% of them avoid spending time and hence bid directly according to the client’s proposed solutions. Besides time constraints, the interviewees also mentioned that most of the time, in public tenders, even if they send a side-offer to the client with allegedly more efficient solutions, the chances for the client to adopt them are slim.

Regarding knowledge transfer, the results from the interviews show that collected production data is always used, but highly related to economy and more general data (e.g., construction cost per square meter), or else, in case of more specific lessons learned, it is often based on informal talks. On the other hand, only 24% of the respondents answered that they always use specific knowledge from past projects in new tenders based on digital databases, as many also answered that they rarely do it, and only 3.4% answered that they never use this type of knowledge. A reason for the not-so-great use of production data for means of lessons learned might be justified on two findings from the survey. The low level of trust in the current premises for ‘data standardization’ - with only 24% trusting it; and the ‘user-friendly’ concern - with only 24% claiming their knowledge-transfer tool to be ‘easy to use’. Further, as presented in the literature review and also stated by some interviewees, it is hard to benchmark production data since ‘every project is unique’. The interviewees’ answers regarding this topic were perceived as vague. Although a few mentioned ‘uniqueness’ as a challenge for wider use of more specific ‘lessons-learned’ from production data, others were perceived as possibly too senior to acknowledge the issues related to the work dynamics of a more specific and hands-on routine. As senior business managers, it is very possible that their attention prioritizes top-management, strategic issues over specific aspects of technology dynamics.

5 Discussion

RQ.1) In a changing building sector, how is the contractor's responsibility framed by the climate agenda, business dynamics and traditional tendering practices?

As stated in the methodology chapter, RQ1 seeks to explore the context in which the contractors are framed to pursue change for more efficient construction. With that goal in mind, the reasoning for this research question has been divided into four parts. First, it tackles *the climate agenda* regulations, exploring the findings related specially to embodied carbon targets and the authors' interpretation of the possible consequences of these in the Swedish building sector. Secondly, a reflection on the *business dynamics* interrelated to building projects is undertaken. Thirdly, findings related to *tendering practices* and perceived difficulties associated with client requirements are exposed. And lastly, a summary of how all the previously mentioned subjects play a role in framing contractors' responsibilities in the building sector.

A) The Climate Agenda and Embodied Carbon (A1-A5) targets

It has been presented through the literature review that the concept of Sustainability is supported on 'economic', 'environmental', and 'social' dimensions. Further, it has been argued that these principles guided the United Nations 2030 Agenda for Sustainable Development, designing "a plan of action for people, planet and prosperity". As part of these initiatives - and pushed by the global warming concern - the climate agenda has urged societies and governments all over the world to pursue change for a more sustainable future. Inspired by that, Sweden has been adopting a number of regulations to address such issues, and as a product of these, industry roadmaps with ambitious embodied carbon reduction targets were recently conceived.

Such significant attention to embodied carbon impact has been on focus of diverse recent papers produced by a number of international authors and organizations. It has been argued that the operational emissions - traditionally more relevant due to the long-term impact - have been reducing considerably over the last decades. Accordingly, as this reduction proceeds, the embodied share of the whole - which has previously been disregarded at large - becomes increasingly relevant. To illustrate this, it has been shown that the embodied carbon impact arising from manufacturing, transporting, and processing of construction materials (for buildings and infrastructure), accounts for approximately one-fifth of Sweden's annual CO_2 emissions.

Moreover, the growing consideration to embodied impact by authorities can also be justified on the belief that often the sources of these emissions are not economically attractive to be reduced. In regard to that, many authors claimed that the economic aspect is often the driving force for sustainability. Following that logic, it is reasonable to think that the *operational CO_2 emissions* have been reducing significantly over the year because building performance is commonly associated with economic savings with energy bills. On the other hand, since the reduction of embodied carbon emissions in buildings is often associated with extra costs, it seems logical to believe that kind of change will hardly be addressed by project actors based solely on their goodwill. In other words, it is presumable that *the invisible hand of the market* will not solve such an issue by its own means unless governmental measures are implemented to ground fair competition on these same fundamental conditions.

In Sweden, such measures came in the form of *the climate act* regulations and subsequent *embodied carbon to practical completion* (A1-A5) targets. As revealed in the review, based on this, the building sector has compromised to start conceiving building environmental declarations by 2022. Following that, a systematic cut of the A1-A5 emissions will be commenced, reaching 50% until 2030 and achieving carbon neutrality by 2045. However, it has been demonstrated through the review of recent studies that 80% of all *embodied carbon emissions* come from the building materials extraction to manufacturing (A1-A3), while 9% of these emissions are produced during transport (A4), and 11% during the construction process (A5). Suitably, construction sector roadmaps are strongly basing their proposals on new industrial ways to manufacture building materials. It has been showed in the literature review that greener production methods - such as electrification, biofuels, and carbon capture - are at the center of these roadmaps strategies.

It is important to consider, however, that although these regulations and roadmaps are focused on *embodied carbon emissions*, those are certainly not the only relevant sustainability factors playing a role in the building sector. However, this study strongly emphasizes this subject over others since these targets are part of the pressing climate agenda and are presently introducing considerable challenges for building contractors over the next coming years. Nonetheless, that does not mean that embodied CO_2 should be advocated over the prejudice of other relevant features of the building. On the contrary, it has been acknowledged throughout this study that only by considering diverse, relevant criteria during the building development, direct and indirect stakeholders' interests can be properly attended in a more valuable building product. With that in mind, literature regarding *multi-criteria decision analysis* (MCDA) has also been reviewed and is advocated as an interesting approach when it comes to the development of building products. Undoubtedly, such multi-criteria approaches have the potential to support decision-makers to better evaluate different options with a system that weighs diverse variables simultaneously. These methods provide a more holistic view of a number of design intentions, better informing decision-makers of their prospective outcomes.

As a matter of fact, in line with that narrative, one could reason that the current governmental strategies proposed through regulations and industry roadmaps in Sweden must be tackled carefully. If the upcoming requirements are set based solely on A1 to A5 embodied carbon impact and LCA results, it may give the wrong incentives for the involved project actors. As it is designed today, these strategies seem to disregard the possibilities of many negative outcomes that these requests can produce when implemented at a large scale, ignoring other relevant criteria. To mention an interesting example, the 'biofuel' proposition, which is cited by many roadmaps (e.g., Karlsson et al., 2020), if employed as it is needed (due to the pressing agenda), it might be challenging to be practicably implemented due to regional 'land-use' limitations. It is reasonable to think that a considerable area will be needed to supply enough fuel for such a substantial energy demand. Other relevant considerations regard *operational carbon* impact, as a prioritization of LCA's results (embodied) may lead to a short-term focus, possibly producing adverse effects on buildings energy efficiency, and hence increasing the impact of buildings on a long-term perspective. Similar trade-offs can also take place on other dimensions of Sustainability. The 'economic' dimension, for instance, brings to the discussion perhaps the most relevant aspect. As stated in the "Klimatpolitiska rådets rapport 2020" (Bonde et al., 2020), "major investments will be needed in new installations and infrastructure, in particular electricity networks, but also in CCS and hydrogen infrastructure, for which funding is currently uncertain". Further, it has been claimed that "the conditions for making the necessary investments pose a particular challenge that is often highlighted by industry representatives" (ibid). Accordingly, it is reasonable to believe that the economic aspect poses a massive challenge for the feasibility of such plans, as building costs and, consequently, Real Estate prices might increase substantially with this new demand for greener, pricier materials. After all, someone will have to pay for the industry transformation, as "*there's no such thing as a free lunch*" (Friedman, 1975). Consequently, if there is not enough subsidy from the state to fund this change, then it is also reasonable to expect a considerable social and economic impact due to inflated housing prices. And that, in turn, may well turn the whole plan unfeasible.

B) The building sector business dynamics

When it comes to the Construction Industry, it has been claimed that the main driver for sustainability is the economic. In this study, data collected both from the interviews and the survey further reinforce such perceptions. The contractor's respondents clearly stated that their priority is to deliver what is contracted with the lower possible construction costs. Hence, there is not much incentive - other than the ones grounded on regulations and standard agreements - to deliver more costly solutions.

Such understanding is not surprising. It can be reasoned that in a Lean perspective, anything that is not perceived as valuable by the customer and is not part of the Project scope should be considered as productivity waste (Koskela, 2000). "If it does not add value, it is waste" (Ford, 1926), and as of consequence, if 'Clients' do not establish higher demands for greener solutions through stricter procurement requirements, that is because they are not willing to pay for something they do not Value enough. Such viewpoint is shared by Skalén et al. (2018) 'Service logic' perspective, which argue that Value is only created when the customer perceives it. Accordingly, one can evidently expect that a pricier solution will not be funded by Contractors whose main purpose is to deliver what has been contracted and paid for.

There is, hence, an overall understanding that Clients are, instead, the ones supposed to push change for more sustainable development. That point of view is driven by the fact that clients are the project owners, and as such, detain the power to establish higher environmental requirements for buildings projects already from its initial conception. However, many who argue that frequently ignore the fact that - although labeled as 'Clients'- these actors are in fact 'Project developers'. As such, more often than not, they are not the end customers, especially in the building sector. Such project-owners normally develop facilities aiming to sell or rent these assets for their customers - individuals or other organizations (which, by the way, might well rent the space yet for another user). 'Clients' in the building sector are, hence, most of the time mediators. Players who do business and profit over the supply of basic society demands, such as living, working, studying, etc. As such, their representatives are also often framed through economic obligations. Therefore, what developers perceive as value is, in fact, mostly influenced by their analysis of the Real Estate market and what they believe that potential customers recognize as valuable. It is, hence, as usual, most often based on market demands and economical driving forces. Furthermore, these fragmented commercial relationships between different project stakeholders very often prioritize short-term gains over long-term value, thus contributing to the problem. Responsibility for unsustainable early decisions is often passed along to other actors, and inefficiencies are hence not acknowledged by decision-makers to act better informed on next opportunities. These conventional business models also do not give incentives for shared knowledge and collaboration since each actor defends their own commercial interests, mitigating their risks by allocating it to others.

As a result, such commercial dynamics driven by fragmented interests and market demands end up playing an important role on how building products are developed, and the environmental impact resulted from that.

C) Tendering practices and Client requirements

Many authors claim that clients have an important role in promoting a more sustainable construction practice. One recurring subject highlighted on this matter relates to procurement methods and client requirements. Regarding that, pertinent data from the survey reveals that Contractors, when asked what kind of requirements most often impact buildability, returned with 'thermal & acoustic', 'facade details', ‘structural frame’ and ‘materials specifications’ (between others). When compared with the analyzed tender documents, it seems that data converge considerably since these requirements are largely present in those. ‘Acoustic requirements’ could be found in 41.7% of the analyzed documents; ‘energy consumption’ - which can possibly convey with ‘facade’ - in 58.3%; ‘structural framing’ in 41.7%; and lastly, ‘materials’ and ‘components’, in 58.3% and 66.7%, respectively.

Another matter regards how detailed the solicitations are in tender briefings and how impactful these are in regard to contractor’s flexibility to propose potentially *easy-to-build* solutions. From a contractor’s perspective, it can be claimed through the collected data that the overall quantity and level of details, particularly when it comes to *descriptive* ‘technical requirements’ (instead of performance requirements), is a relevant aspect. It is claimed that this type of requirements ‘tells contractors how to build’, instead of letting them make use of their expertise.

D) How is the Contractor responsibility framed?

As previously narrated, the ambitious climate targets impose a considerable test for the building sector in the upcoming years. It has been reasoned that the economic factor will pose a considerable challenge for the success of this mission. At the same time, conventional fragmented business models in the building sector are perceived as deficient and make sustainable progress even more challenging. Furthermore, these commercial practices help produce procurement practices that do not foster trust and collaboration. Instead, the perception of risk and individualistic economic motivations often lead to bureaucracy and contractor’s inflexibility being produced through complex tendering processes and overly specified client requirements.

RQ.2) Is there a link between Sustainability and Buildability that can serve as a driver for change?

As previously stated, sustainability is a quite broad concept, often associated with ‘economic’, ‘social’ and ‘environmental’ aspects - or dimensions. This study focused on the environmental dimension in the form of reduction targets for embodied carbon emissions. It has been supported that the economic factor is often the main driving force for sustainability. As such, it has been argued that in order to promote sustainable practices, it is often a good practice to find the economic incentives for that. Likewise, the other way around is also true, as higher costs often turn sustainable practices unattractive or even unfeasible. As exemplified previously, potential inflation in building materials - and subsequently increasing housing prices - may well turn the decarbonization roadmaps unfeasible, as it may lead to complex social issues.

As such, to promote sustainability it is very important to take in consideration all the dimensions and think carefully on diverse possible consequences, as often one type of initiative might create a negative impact on others. There is, consequently, a need for the identification of practices that are beneficial for the three dimensions simultaneously. Or at least ways to compensate one another.

Accordingly, it is supported that ‘Buildability’, as means for ‘ease of construction’, can promote such ‘win-win’ situations. As shown in Table 6.1, DfMa, in addition to solid supply chain management (SCM) and site logistics, can represent an opportunity for benefits on the three dimensions of sustainability. That is due to the understanding that a simplification of the construction process can certainly lead to reduced waste in resources - both in terms of materials and processes. Besides, it must be considered that some of these gains are not so explicit or easily measurable. A good example is a simpler data analysis resulted from standardizations that can likely aid on continuous improvement measures, creating value on a long-term perspective.

		Tactic tool (Design criteria)	**Strategy** (approach)	< How to	**Sustainability Goals**		Most-benefited
Stage	Processes	Why >	< How to	Economic	Social	Environmental	**Stakeholder?**
Development	Design & Planning	**Simplify & Integrate processes***	Faster inform, reducing waste in process	**- Cost**	Work Environment	- Emb & Ope	**Contractor**
Construction	Materials Purchasing	MDD (Material-driven Design)	Reduce materials emissions	+ Cost	-	**- Embodied**	Environment
	Production	**DfMA*** + SCM + Site Logistics	Simplify Site mngt. thru Buildability	**- Cost**	Health & Safety	- Embodied	**Contractor**
	Production	**DfMA*** + SCM + Site Logistics	Reduce waste thru Buildability	**- Cost**	Health & Safety	- Embodied	**Contractor**
	Production	**DfMA*** + SCM + Site Logistics	Optimize transports thru Buildability	- Cost**	Traffic & Accidents	**- Embodied**	Environment
	Production	Procure green energy & processes	Use fossil-free transports w/ machinery	+ Cost	-	**- Embodied**	Environment
Service Use	Performance in use	DfOP (Operational Performance)	Improve energy efficiency in Use	**- LCC (ROI)**	-	- Operational	Property owner
	Performance in use	DfOP (Operational Performance)	Improve acoustic efficiency in Use	+ Cost	**Noise**	+ Embodied	User
	Maintenance in use	DfM (Maintainability)	Reduce Waste in Materials & Tasks	**- LCC (ROI)**	Health & Safety	- Embodied	Property owner
	Maintenance in use	DfM (Maintainability)	Optimize transport *(need less services)*	- LCC (ROI)	Traffic & Accidents	**- Embodied**	Society
	Remodellings in use	DfAD (Adaptability & Flexibility)	Reduce Waste in Materials & Tasks	**- LCC (ROI)**	Agile facilities	- Embodied	Property owner
End of Life	Disposal	Dfd (Disassembly / Deconstruction)	Reduce Waste in Materials & Tasks	+ Cost	Noise & Dust	**- Embodied**	Environment
	Disposal	Dfd (Disassembly / Deconstruction)	Optimize transport	+ Cost	**Traffic & Accidents**	- Embodied	Society
***** Buildability approach** *(often win-win situations, specially in perspective of embodied carbon)*				*//*	*** It may vary, depending on certain conditions*		

Table 6.1: Example of early-stage tactics to achieve Sustainability, conceived by authors using a FAST technique

It is important to reason, however, that a number of studies claimed that off-site methods are not always the most efficient solution, as “prefabrication saves time, but not necessarily cost” (Shayboun, 2018), and traffic impact due to bulky components and heavy freights might also pose a challenge to social and environmental aspects. To deal with that, many authors and industry representatives suggested the use of ‘construction consolidation centers’ (CCC’s), although there is no consensus on how economically attractive these solutions are for main contractors. The conflicting opinions regard especially the poorly estimated costs and complex realization of savings from it, which, interesting enough, can be attributed at large to the characteristically complex construction methods - that a ‘buildability’ tactic could certainly help alleviate. Additionally, as argued by RIBA plan of work (2020), there must be considered that off-site construction can be exponentially benefited by supporting initiatives involving the wide industry and public authorities. By creating the right conditions for industrialized mass production via long-term ‘pipelines’, the industry can potentialize standardized prefabricated components for diverse Projects, mitigating the widely known limitations of the project-based production and increasing the benefits. Such initiatives might become more feasible and attractive if more regional actors adopt such methods, as it seems to be the ongoing case in the United Kingdom.

Moreover, the collected data in this study support that many practical principles of buildability foster resource-efficient production practices, and therefore can produce improvements in all three dimensions of Sustainability. As defended in Table 6.1, a Design-for-Manufacturing (DfMa) strategy alongside site logistics and Supply Chain Management (SCM), potentially provides improvements in all three dimensions (in green). The second row, ‘Materials-Driven-Design’ (MDD) suggests that approach is highly beneficial to ‘environment’ dimension (since materials extraction and manufacturing - A1 to A3 - represent estimated 80% of embodied carbon impact), but much probably, as seen in the literature review, negatively affect the ‘economic’ aspect due to the expected higher investments in greener materials manufacturing via electrification and biofuel employment. Hence, that row is in red. The same applies for the sixth row, with higher costs expected for the use of green energy for transports (A4) and construction processes (A5) - e.g., equipment’s and machinery - which as seen in literature, represents 11% and 9% emissions, respectively, of the estimated yearly embodied carbon emissions from the building sector. Other Design strategies are listed in the table, along with their expected impacts on Sustainability. Rows in yellow demonstrate the approaches that are expected to represent gains in all dimensions, although with a long-term perspective of ‘ROI’. Examples being ‘Design-for-Operational-Performance’ (DfOP), ‘for-Maintenance’(DfMA), and ‘for-Adaptability’(DfA), as these are expected to produce cost savings during the use-stage of the building, thus compensating over time the initial investment. Lastly, a ‘Design-for-Disassembly’ (DfD) tactic is expected to represent costs, although highly desired to the ‘environment’ dimension, due to the reuse of materials and components opportunity.

On the other hand, the previously underlined Design tactics (DfMa, DfOP, DfM, DfAd, DfD, etc.), although often interesting to Sustainability, also pose risks that need to be acknowledged. Designing for maintenance and operational performance, for instance, will certainly demand more detailed frames, smarter shafts, and thicker insulation materials, etc., which might lead to some negative effects on embodied carbon and LCA results due to a higher quantity of resources consumed in the production of more elaborated components. It can be reasoned that, partly because of this, over the last years, the embodied carbon impact has slightly increased, while the operational impact has strongly reduced, as revealed in literature. It is believed that a growing awareness towards building solutions that leads to less energy consumption - more expressively with ‘HVAC’ - has given economic incentives for property owners to invest in these more elaborated solutions, especially on the building enclosure components. Such interpretation is endorsed by interviewees’ considerations that clients have been more aware and asking for requirements that lead to operational performance. It is also strengthened by the considerable amount of ‘client’s requirements’ present in the analyzed documents that clearly aim for such matter. That perspective is reinforced by RIBA plan of work (2020) and other papers with the claim that, as the operational impact has been attended and reduced, more significant the embodied carbon impact has become in relation to the whole.

Such narrative serves to highlight how complex and multifaceted is a building project and its outcomes on other stakeholders - including the environment and the wide public. It can be argued, hence, that a multi-criteria decision analysis (MCDA) is the most appropriate method to evaluate the Design efficiency and life-cycle impact of buildings. However, as shown in literature, International and Swedish initiatives have recently been guiding efforts towards a lower embodied carbon impact - which, as mentioned before, is perceived as a challenge since it represents an economic burden (in contrast to operational). As previously highlighted, ongoing changes on regulations in Sweden will demand embodied-carbon-to-practical-completion (A1-A5) declarations as a requirement for building permits already in January 2022. That same ‘fossilfri’ program, sets to 2030 an ambitious goal to 50% carbon reduction, and to 2045, carbon neutrality. It is adopted, hence, an imposing measure to deal with the part of the problem that is not economically driven. Such initiatives, although certainly longed-for, must be thoughtful. If intelligent criteria are not well assessed through the assessments, then these requirements might end up giving undesirable incentives. Other than ignoring the eventual consequences on other dimensions of Sustainability, such demand might also lead Real Estate developers to prioritize embodied carbon over an operational efficient building, especially if there is no intention from the developer to keep the asset over the whole life cycle (i.e., apartments for sale), and thus, not much importance given to long term performance and energy consumption optimization. In other words, if it is not carefully conceived, this regulation might lead to a setback on the recent operational gains. Another complicating factor is that, as shown in the reviewed literature and in RQ1, the premises and assumptions in LCA are often debatable, especially with the partial information available in the early stages of the Project, when building permits are necessarily addressed and the building declarations will be demanded.

Furthermore, it is well-known that varied interests from different discipline specialists often lead to ‘short blanket’ dilemmas in the Design development stage. For instance, the Architects may design certain details that are not buildable in the perspective of the Structural Engineer or the HVAC specialist. Decisions are then, taken prioritizing certain trade-offs that, unfortunately, are often approached not sufficiently informed and, every so often, highly unaware of the consequences of those choices. In the given example, a question that could be done is: the detail provided by the Architect is worth the extra work to build? Does it add value?

That is further addressed by one of the interviewees claim that Clients often have ‘big dreams’ developed by consultants, and it ends up eventually being reduced due to available budgets. Time constraints during further limit the available room for debate for the best-fit solutions since in DB, construction is commenced along with Design (Lam et al., 2006). Such constraints, as of authors’ work experience, can be justified by the fact that ‘time’ in Construction Projects is a highly relevant variable. Not only due to high fixed costs, that every so often consumes profits via delays, but also because of a building project’s financing system that is typically based in a primarily negative cash flow - as a consequence of the often massive outflows for land acquisition and other expenditures on projects ‘month zero’. Such initial investment will typically only break even after construction is commissioned (habitually in apartment buildings for sale, in which financial institutions pay the developer at 'keys-time', further taking on tenants' payments through long-term mortgages). There are, of course, varied business dynamics and, accordingly, various financial methods that differ greatly from the previously mentioned system. However, it can be safely argued that as of general rule, better financial results are reached if the lead-time from land acquisition to construction delivery is shortened, and consequently, higher margins are achieved (especially in countries with higher interest rates). Hence our justified effort to simplify the early-stage processes and hopefully achieve a more dynamically informed, simpler, faster, valuable, and sustainable building product development.

By overviewing a broader picture of building project's dynamics, we hope to shed light on:

- Design tactics cause-effect in the three dimensions of Sustainability, as shown in Table 6.1
- Opportunities to deliver a more sustainable building through a Buildability / 'DfMa' approach
- Opportunities to deliver a more sustainable building through Production knowledge transfer
- Design decisions complexity, often held uninformed of consequences
- The importance of Multi-Criteria Decision Analysis (MCDA) in building projects
- The overall lead-time pressure from land-acquisition until building delivery - intensified in 'DB'
- The necessity to reduce building costs to give room for greener materials investments

In resume, this section supports that a Buildability approach helps to deal with sustainability issues in the building sector in different ways. First, through the practical principles of 'simplification' and 'ease of construction', which, as showed in Table 6.1 and supported by several authors and industry studies, can lead to less waste, productivity gains, and overall improvements in all three dimensions of Sustainability. Second, by supporting knowledge transfer from Production back to Design, in order to influence these practical principles to be adopted in the early stages of product development. Third, by facilitating multi-criteria decision assessments via production data, providing the right information at the right time. And finally, to achieve through all the previously mentioned approaches, a product development that is suitable to foster 'modern methods of construction' (MMC). By that, possibly provide vital cost reductions to compensate the rising demand for costlier greener building materials and processes (i.e., machinery electrification, carbon capture, deconstruction, etc.) that are proposed by current decarbonization roadmaps. Lastly, it is argued that only by taking a holistic 'economic' approach, such roadmap ambitions can be met.

RQ.3) How can contractors promote resource-efficiency in the building sector?

Literature supports that 'Design-and-Build' can be seen as a procurement approach to provide contractor's independence, granting more flexibility to propose 'Buildability' solutions early on project development. However, although DB is largely utilized in Sweden, interviewees claimed that the 'concept design' and 'technical requirements' provided by clients and consultants in regular DB tender briefings - without Partnering - often limit the contractor's ability to provide the most buildable and 'resource-efficient' solutions.

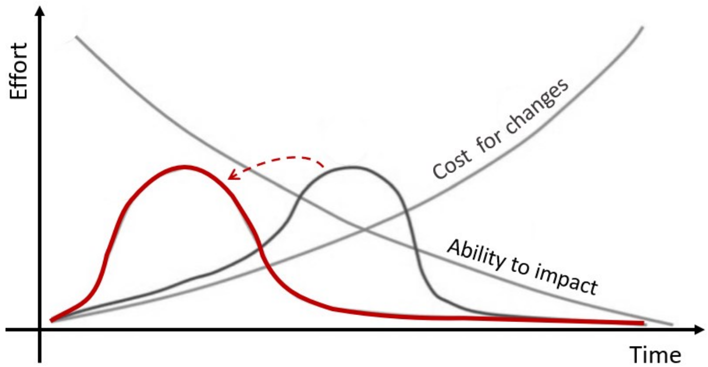


Figure 6.1: The 'Effort Curve', showing the usual Design development and the effort for earlier decision making. Conceived by the authors, based on Macleamy (2004)

It is interesting to note, however, that according to the reviewed 'Buildability' literature from the early '80s, the idealization of the DB method was, at great extent, already an answer to the early involvement and contractor's 'independence' dilemma, hoping to enable the desired knowledge-transfer of production expertise in design. It seems clear though, that after three decades, the impasse between Architects and builders regarding the Design outcomes in Production is still a substantial concern in the development agenda.

Driven by such claim, a number of authors and industry representatives have been advocating for the so-called 'Early involvement of Contractors' (EIC), defending the perspective that Contractors can contribute with their Production knowledge already in the earliest phases of project development, particularly in concept-design and client requirements preparation. It has been argued that Contractors can be helpful in conceiving a more valuable project outcome by taking into consideration buildability aspects before tender briefing is 'set in stone'. Simonsson (2011) survey supported this, stating that according to contractors, the top factor to influence 'Buildability' in Sweden is 'EIC', and Shayboun (2018) added that the quality of design documents and the designer's ability to provide buildable solutions are important factors influencing on 'costs variance' and 'client satisfaction' indicators. Such perspective is clearly confirmed by empirical data since many interviewees mentioned that design delivered by public clients on regular DB building tenders is often seen by builders as sub-optimized and inflexible in buildability traits. Yet, according to interviewees, when it comes to public clients, it is quite challenging to influence changes in tender briefings due to 'public procurement act' (LOU) restrictions. That is verified in the survey result, as Contractors clearly avoid proposing changes on public tender briefings (73%) to instead focus resources on creating the perceived 'most competitive bids' - based solely on what is required by the client in their original briefing.

As a matter of fact, it has been observed that Contractors, as expected, use all their competence to obtain a competitive advantage on Tenders. A number of the interviewed business managers strongly endorsed the belief that their distinction is the capacity to propose winning bids, particularly on DB ('totalentreprenad'). Thus, the less developed the tender briefing, the more room to create smarter, competitive proposals.

- “That is what we are good at.” – An interviewee claimed.

It seems clear, though, that the contractor alleged competence refers not only to the development of building products but also to a smarter interpretation and cleverer handling of bureaucratic tendering processes. From their explanations on this subject, it gave the impression to exist opportunities - sometimes through client requirements contradictions and briefing vagueness - to explore certain breaches, thus managing to gain a certain competitive advantage that others were not able to see. That, according to interview findings, seems to be ‘part of the business’.

It can be argued, however, that such complexity in commercial practices, is in fact ‘part of the problem’. A complex and bureaucratic procurement process, at large extent limits the competition - and consequently innovation - as it creates challenges for smaller and less structured players to take part in this inefficient and costly bidding process. On the other hand, it can explain why large Swedish contractors’ respondents, more explicitly in the survey, revealed a surprising ‘satisfaction’ with a recognized ‘resource-consuming’ tender process. In regard to that, it is important to remember that this study contacted only the leading Swedish players, with the largest market share. As such, it is indeed quite plausible to not feel ‘dissatisfied’ with how the tender process goes. As one mentioned in the interview, “construction is a complex business”. And for them, that seems to be working just fine.

Such reasoning, although speculative, seems to go in harmony with an industry that is well known for being traditionally conservative and, to a great extent, not much proactive and innovative. In fact, the so called ‘market-oriented’ - which could also be described as ‘the strategy to not engage change until customer demand’ - seems to be adopted in the industry at a large.

Yet, this complex tender process appears to produce a somewhat obscure procurement dichotomy, where clients are fearful of being too vague in tender requirements, possibly granting openings for builders to explore additive fees, while contractors are unpleased with exaggerated details and ‘special requirements’, that are every so often added even on top of ‘standard agreements’. A practice that seems to be increasingly adopted by clients and that is often perceived by Contractors as bureaucratic, inefficient, and unnecessary.

Some mentioned that a way around such an issue is through the adoption of *Partnering* project delivery. Still, although most interviewed Contractors firmly support it - considering it can provide the best value for the money through Buildability - they also perceive that over the last few years, public clients have been asking for it less. Many contractors claimed there is, unfortunately, an ongoing stepping back into the previously *regular DB* without EIC on building projects. Nonetheless, such viewpoint regarding current *Partnering* employment appears to vary considerably depending on different Swedish regions. It has been claimed that a stronger setback on Partnering practices is perceived in bigger municipalities of the West (e.g., Gothenburg) and South Sweden (e.g., Malmö and Lund), while smaller municipalities remain procuring with it. One experienced interviewee pondered that may be for the reason that some larger municipalities have been increasingly hiring construction experts. Based on that, these clients believe in holding the needed expertise to develop the project by themselves ‘in-house’, while counting with less risk of price uncertainties. Such opinion, although limited since most interviewees did not risk speculating why goes in harmony with Simonsson et al. (2011) reasoning that Clients (developers) do not value EIC because they believe to “have the competence themselves” (ibid). Such findings come to reinforce contractor challenges to influence clients during the early stages and promote Buildability. It seems clear that, although many authors advocate for EIC and *Partnering*, these practices cannot be counted as sole solutions to foster Buildability in building projects, as its adoption depends greatly on the type of Client and their belief that it is relevant to do so.

Therefore, if Contractors desire to influence early on project development, another solution must be sought.

From here on, one could use this obstacle to justify an impediment, concluding that Clients are responsible for tender briefing inefficiencies. Thus, they need to change their unsustainable practices. However, a way around that limited narrative is supported to exist in this study. In that way around, the Contractors undertake an honored central role for a change. Such an approach is backed by the argument that Production-data, a valuable asset to promote the desired Buildability, is in control of Contractors. Therefore, it is believed to be in their range the opportunity to influence change on actors that are arguably less aware of the benefits of more efficient modern methods of construction (MMC) - as of Contractor's perspective.

With that said, it is argued that, although public clients currently do not really allow many opportunities for contractors to influence tender briefings, the possibility exists. In fact, according to the survey with contractor's business managers, only 28.57% of respondents answered that they do critically analyze tender briefings and propose side-offers for the public client (on regular DB without Partnering), while 71.43% avoid spending time and just bid on the original brief. Accordingly, there is a lot of room for improvement.

The challenge is hence, how to improve it. This study supports that, as mentioned before, and endorsed by Lam et al. (2006), Architects and other consultants are subjected to payment dynamics that limit the available time to work on designs. Therefore, there is not enough time to explore different solutions and 'what-if' alternatives, considering diverse criteria that should be addressed in a building project.

Therefore, at hand is an opportunity to offer a bidding strategy that aids contractors with a faster, dynamically integrated, and better-informed process, allowing multi-criteria to be accessed when such decisions can still be addressed and improved. Such a strategy is believed to be achievable by using current cutting-edge technology that can greatly empower the process by "combining human learning with computational intelligence to solve the related construction planning problems" (Zhou et al., 2017).

RQ.4) What kind of 'AI-tools' can aid contractors processes to facilitate Buildability and Sustainability?

The following three areas are identified for possible improvements, and based on that, a roadmap of AI-tools is subsequently designed to frame all these solutions together in a holistic strategy.

RQ.4.1) Information-flows

From the analysis of tender documents, as well as the data collected from interviews and survey, it can be supported that the way Clients deliver requirements for Contractors, as well as the subsequent flow of that information throughout the elaboration of proposals and placing of bids, is highly resource-consuming and inefficient – especially, but not limited to, public building procurement on regular DB.

Accordingly, it is supported that, without much effort, with available and inexpensive technology, such tender documents that often arrive in PDF's - or even in scanned, raster-format images (as of survey and document analysis findings) - can be automatically transformed into open-format, editable texts, and machine-readable data, through what is labeled in this study as a 'PDF-readable tool'. In more technical terms, as briefly explained in chapter 3.4.1, this process is conducted with an 'OCR' (optical character recognition) tool, adopting five systematic steps to perform the conversion with maximum accuracy and categorizing the data accordingly to 'AMA AF' format, and other structures complying to the studied organization internal demand.

RQ.4.2) Concept-Design Integration

The study clearly demonstrates that one issue regarding tendering is that many discipline experts need to collaborate to create a valuable solution. Occurs, though, that many times different actors such as Architects and Structural Engineers have different priorities and viewpoint on the best solutions. Designers often focus primarily on aesthetics, while others criticize the consequences of this or that on final Project outcomes. As argued in chapter 3.2.1, these 'ping-pongs' between different disciplines experts to conceive design, is often inefficient as it is not entirely integrated, dynamic, and streamlined. In part because of that, the task to 'conceive a competitive proposal by involving multidisciplinary experts' has been rated highly resource-consuming in the survey, as well as mentioned in interviews. Survey data also showed that most contractors prefer to bid directly on client's requirements instead of proposing side offers, which collaborates with that viewpoint. Accordingly, it is believed that such kind of solution to simplify and speed up proposals could allow contractors a way more efficient way to conceive side-offers dynamically and on demand.

RQ.4.3) Knowledge-Transfer

The last area of improvement is the most challenging one. Knowledge transfer seems to be around for quite some time, with many initiatives that seem to not be working up to its potential. However, as technology is developing, it is believed that most of the perceived barriers for it to reach maturity are becoming possibly resolvable. The buildings 'uniqueness' factor, for instance, often mentioned as a major issue concerning lessons learned difficulties, can be addressed if specific parts of the whole are categorized to be benchmarked with these same specific parts of other buildings. After all, buildings are not really that unique, containing in big parts, repeatable services, and processes. Hence it is a matter of searching through projects and separating 'bananas from apples', to further compare accordingly. Something only a machine can do. Another issue regards the 'user-friendly' aspect of these tools, as clearly stated in the survey. Hence, special attention to these is suggested when conceiving such a tool.

6 Conclusion

This study has shown that 'Early involvement of Contractors' (EIC) practices to influence on Tender briefing, although broadly supported by Contractors, are highly limited in Sweden due to the 'Public Procurement Act' (LOU). Also, *partnering* delivery methods, which is commonly referred to as the way around 'LOU' to provide 'Buildability', also do not seem to find unanimity with many public clients.

Consequently, as of today, none of these possible strategies to promote 'buildability' and 'sustainability' can be counted as definitive solutions for the previously mentioned sector goals, especially at the desired speed and scale. Another complicator factor is that large contractors are perceived to be 'satisfied' with the current tendering processes, thus endorsing 'business-as-usual'. That can perhaps be justified on to the lack of incentives to change or to the unawareness of possible methods for improvements. Most probably, both.

However, although it is noticeable that the journey ahead is quite challenging, this study chooses to take an unusual approach and suggests that Contractors can assume for themselves a central responsibility for sustainable development. This choice is grounded on the understanding that contractors are the ones possessing the most promising (and hardest to achieve) knowledge of production methods. Contractors are also the project actors with the highest potential to collect valuable production data that can lead to Buildability and continuous improvement, and as of result, an attempt to promote the so desired 'resource-efficient' construction process.

This thesis supports, thus, that for the desired change to happen, a better-informed procurement must be proposed where decision-makers can have the right information at the right time, being able to make more conscious and smarter decisions through a 'what-if' approach, acknowledging the consequences of each of these upon different criteria, by evaluating the parameters altogether with a simplified and dynamic way.

With that in mind, this thesis is concluded by suggesting a framework (Figure 7.1) for the application of the concepts that are believed to, as supported by this research reasoning, aid contractors on developing more sustainable and valuable buildings. Further, the suggested framework also serves as a roadmap for the implementation of these solutions, as observed in the numerical order of such AI tools, on the lower part of the figure.

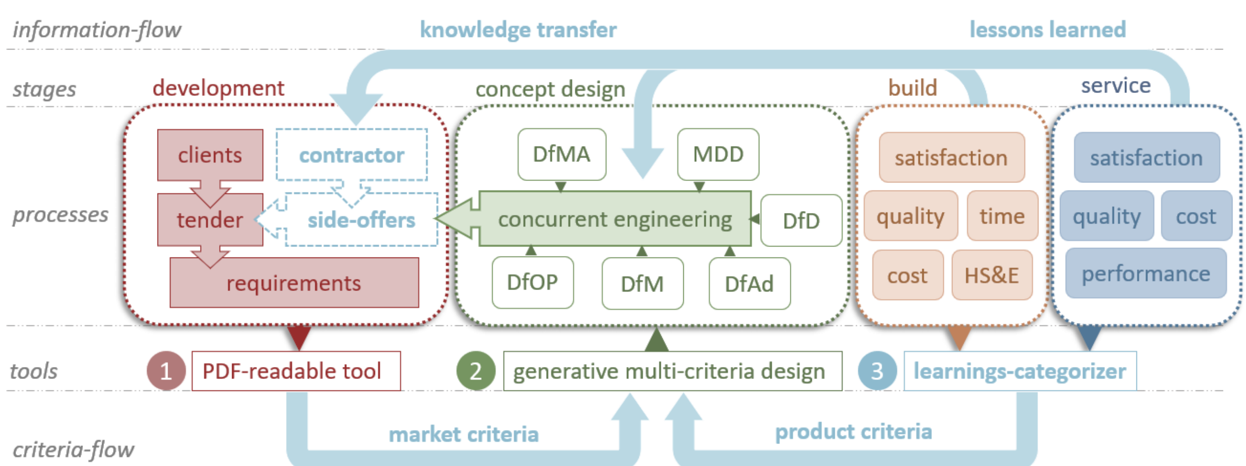


Figure 7.1*: Proposed AI-tools roadmap to aid informed building procurement*

As demonstrated on the right side of the figure, data achieved from the production and use stage - here labeled ‘Product criteria’ - is transferred to feed the proposed multi-criteria design. That is done by inputting these different collected Production and Aftermarket-data as parameters in a generative design tool. The same goes with the output data collected from tender documents (client requirements), in the left side of the figure - here labeled ‘the Market criteria’ - which also comes in feeding this multi-criteria Design system, in the form of additional ‘client requirement parameters’, to be processed along with the previously mentioned Buildability and Sustainability criteria, related to ‘Product’.

To aid in collecting and categorizing data from both ‘market’ and ‘product’ criteria, it can be noted that two tools - 1 and 3 - have been proposed. Tool 1, as previously explained, is a ‘PDF-readable’ tool – based on OCR and floorplan recognition technologies - that aids the contractor by automatically collecting data from raw documents and raster drawings, converting them, and categorizing in a format that is machine-readable, based in a structure in AMA format, simplifying and possibly allowing for benchmarking tendering information. As previously discussed, such documents sometimes are delivered by clients quite disorderly and, as revealed in the survey, working with these to obtain the actual requirements information is unanimously resource-consuming.

Tool 3, on the right side of the figure, attend a similar but quite more challenging purpose, as it aims to provide a solution to search for specific tasks similarities in past projects, avoiding the ‘uniqueness’ factor of construction projects, and allowing hence to compare ‘apples with apples’ in regard to production data.

Tool 2, in which all this data is fed, as explained previously, is a ‘generative design’ solution that makes use of both market and product criteria in the form of parameters to provide as a final goal a side-offer solution that can be offered to clients as early as possible, with enough data to inform and hopefully convince public clients that certain conditions are more valuable and sustainable. By demonstrating through data ‘what if’ conditions, it is argued that Contractors’ can better influence Clients and with less resources.

Ultimately, it is also suggested that the ‘PDF-readable tool’ is a currently easily accessible technology that can be the ‘low-hanging fruit’, serving to reveal the potential of AI to contractors business managers and thus further increasing their interest in the tool 2, and lastly tool 3.

6.1 Future Studies

Even though this thesis suggests a roadmap (Figure 7.1) for the industry to aid informed building procurement, there are still some gaps in the research. Suggestions for further studies and research topics are named below.

- Specific subjects impact of ‘prescriptive requirements’ in buildability and sustainability
- Study on new business models with a ‘servitization’ / circular economy approach, exploring the early stages decisions since land procurement.
- Exploration on the consequence of modern construction methods that might (hopefully) lead to less costly construction. Which stakeholders will benefit from this on the long run?
- Real Estate regulated rental prices and its impact on Sustainability.
- Standardized prefab/modular strategy on national level, for the industry to adopt mass production.

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APPENDIX I

Requirements	Clarification of requirements	
AMA AF	Within AMA AF, in some tenders it is stated that if no requirements are specified, AMA framework must be followed. Exceptions from ABT06 and AB04 are included.	If AMA AF is not used, the requirements are delivered in other documents, such as technical and/or framework descriptions, and/or drawings.
Criteria for tenderers	In 7 tenders the client has set criteria for the contractors.	For instance, in economic terms, different reference projects, organization members etc.
Standards (ISO 9001 and ISO14001)	One tender requires ISO 9001 and ISO 14001 certification, or the organization to be Povelföretag*.	In 4 tenders, ISO 9001 and ISO 14001 are required to be followed for quality and environmental management or alternative**
Environmental certification	3 tenders will be environmentally certified with Miljöbyggnad.	
LCA	Tender 1 requires LCA and alternative solutions if improvements can be made after conducting LCA.	Tenders 4,5, and 6 will be environmentally certified and therefore require LCA.
LCC	In Tender 11 LCC of a Specific Fan Effect is required.	
Social requirements	In Tender 1 there is a section regarding Anti-discrimination in AMA AF, including references to discrimination law and law for minimum wages.	Although the other tenders didn’t include this section in the tender documents, the social aspect regarding equal treatment and anti-discrimination is always covered by LOU.
Acoustic requirements	5 tenders require acoustic performance for some building parts.	In Tender 12, specific thickness of insulation in interior walls without affecting the acoustic performance is required.
Thermal requirements	Tender 7 includes performance requirements (indoor temperature).	In Tender 8 a specific U-value*** and specific thickness of insulation is required.
Structural framing system	Requirements for a specific type of structural framing system	
Materials requirements	Referring to building materials requirements. 7 tenders require a specific choice of building materials.	In some tenders, materials have to be approved by, for e.g., SundaHus or Byggvarubedömningen
Building components requirements	8 tenders require a specific type of material in the building components such as prefabricated concrete, steel or wooden materials.	In some tenders a logbook of materials used in a system is required (SundaHus / Byggvarubedömningen).
Energy performance requirements	7 tenders have energy consumption requirements. Tenders 1, 6, and 7 require lower energy consumption in the buildings than BBR requirements.	Energy consumption calculations are required in tenders 11, 4 and 8. Tenders 3 and 8 require justification of the technical solutions regarding consumption and environmental impact.

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