CHALMERS
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Knowledge intensive design exploration

Integration of data-driven design methods in creative design

Master's thesis in Design and Construction Project Management

ANNA BENDER

DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING
DIVISION OF CONSTRUCTION MANAGEMENT

CHALMERS UNIVERSITY OF TECHNOLOGY
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MASTER’S THESIS ACEX30

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ABSTRACT

Architectural design is a world of divergent solutions, and our built surroundings are the result of design processes where some paths were chosen, and many more were ignored. Continuous development in computational technologies has resulted in methods that provide designers with information about how a building will manage certain investigated aspects, leading to expectations of buildings designed with a higher level of knowledge. This thesis investigates how data-driven design methods should be integrated and used by architectural designers. The aim of the thesis is to provide architectural practice with methods that ensure that knowledge-intensive design exploration can take place as data-driven methods are integrated into their operation. The method of systematic combining between theory and empirical findings is used to ensure alignment to reach this aim. The research was conducted by an extensive literature review, together with interviews and observations at an architectural company located in Gothenburg, Sweden. To further intensify the empirical findings, interviews are held with individuals with experience in data-driven methods from both the academy and industry.

The research show that data-driven methods can contribute to knowledge-intensive design exploration if data is used responsibly through critical evaluation and with strategies that ensure qualitative decision-making. The research emphasizes how data enhance the ability to proceed with design suggestions which previously been hard to verify, leading to extended knowledge by all participating in the design process. When data-driven methods are integrated into architectural design exploration, the research highlights the importance of alignment with current design activities. Previous research shows that tools have not correlated with the reality of architectural design, resulting in that they have not been integrated to a full extent. This thesis suggests that data-driven tools should be evaluated to ensure they foster creative processes and integrated teams. They should be integrated in an iterative loop where feedback is continuously provided for everyone in the design team. To ensure alignment with the specific firm, architectural organizations should integrate change-management in their operation and establish a team responsible for investigating innovative methods and tools aligned with the organization's processes, set values and goals. The evaluated methods should be integrated in eight steps to ensure that all involved in the design process at the specific firm can benefit from data-driven tools.

Key words: Architectural design, Creative design, Iterative design, Data-driven design, Change Management

Kunskapsintensiv utforskning av design

Integrering av data-drivna designmetoder i kreativ design

Examensarbete inom mastersprogrammet *Organisering och ledning i bygg- och fastighetssektorn*

ANNA BENDER

Institutionen för arkitektur och samhällsbyggnadsteknik
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SAMMANFATTNING

Arkitektonisk design är en värld av olika beslut och vår byggda omgivning är resultatet av designprocesser där några lösningar valts, och många fler har ignorerats. Kontinuerlig utveckling av datateknologi har lett till metoder som förser designers med information om hur en byggnad hanterar olika utredda aspekter. Detta leder till förväntningar om en mer kunskapsbaserad design. Denna studie undersöker hur data-drivna designmetoder bör integreras så att de främjar arkitekters möjlighet att hantera de flerfaldiga krav och önskemål som omger den arkitektoniska designprocessen. Avsikten med studien är att förse arkitekter med metoder som försäkrar att kunskaps-intensiv designutforskning kan ske då data-drivna verktyg integreras i deras arbetsprocesser. För att uppnå målet, är teori och empiri systematisk kombinerade. Studien innehåller en intensiv litteraturutforskning och för att få insikt i praktiken, är intervjuer och observationer genomförda på ett arkitektkontor i Göteborg. För att få ytterligare material inom data-drivna verktyg är intervjuer med erfarna individer inom ämnet intervjuade.

Studien visar att om data-drivna verktyg och metoder används ansvarsfullt genom att dess resultat utvärderas kritiskt och används med strategier som främjar kvalitativa design beslut kan de bidra till kunskaps-intensiv designutforskning. Forskningen betonar hur data förbättrar möjligheten att gå vidare med designförslag som tidigare varit svåra att verifiera, vilket kan leda till högre kunskap för alla som deltar i designprocessen. Då tidigare studier visar att i tidigare försök att integrera metoderna har det misslyckats, då verktygen inte varit tillräckligt anpassade för de arkitektoniska designprocesserna lyfter studien fram vikten av att data-drivna verktyg och metoder bör utvärderas så att de främjar kreativa proceser och integrerade team. De bör integreras i en iterativ process där feedback från verktygen kontinuerligt ges till alla designteamet. För att säkerställa att arkitektorganisationer gynnas av data-drivna verktyg, för den specifika firman ha strategier som hanterar förändring integrerat i sin organisation. De bör etablera ett team som ansvarar för att undersöka innovativa metoder och verktyg som är förenade med de processer och mål företaget har med digital utveckling. De utvärderade metoderna bör integreras i åtta steg för att säkerställa att alla som är involverade i designutveckling kontoret har nytta av data-drivna verktyg.

Nyckelord: Arkitektonisk design, Kreativ design, Iterativ design, Data-driven design, Change management

Contents

Preface

This work is a master's thesis carried out at the Department of Architecture and Civil Engineering, Division of Construction Management, Chalmers University of Technology, Sweden. The work started in January 2020 and was finished in September 2020.

I want to thank all my colleagues for always being generous with thoughts, attitudes, and love. I want to thank Jens, Sofia, Tomas, and Erik, for your clear insights. Thank you, Martine, for your commitment in creating good conditions despite strange times. Christian, thank you for giving me peace of mind.

Grandma and Grandpa, thank you for teaching me what creativity and craftsmanship are. Mom and Dad, thank you for your unconditional support and pass forwarding your fighting spirit. Sara, thank you for always bringing me down to earth and for making me realize what's important. Joakim, thank you for giving me coffee every morning and for how you helped me through thick and thin. This work would not have been possible without you.

Göteborg, September 2020

ANNA BENDER

1 INTRODUCTION

The introduction is divided into background, aim and objectives, research questions, focus and limitations, to describe the context of the topic and the problem.

1.1 Background

Contemporary building practice is facing multiple challenges. The last few decades have meant significant changes in social, technological, economic, and environmental requirements and there is a need for implementation of methods that contribute to a better-built environment (Ramsgaard Thomsen, et al., 2020).

Continuous development in information and computational technology offers new possibilities to integrate accurate data in architectural design processes (Sheil & Ramsgaard Thomsen, 2020). Data-driven design methods provide designers the ability to eliminate design paths that do not lead anywhere and make buildings more responsive to its surroundings (Deutsch, 2017).

These methods establish expectations for more knowledge-based design exploration (Agi, et al., 2020). However, recent studies show that architectural practice finds it hard to implement data-driven tools and methods for its current design activities (Brix Purup & Petersen, 2020).

1.2 Aim and objectives

With this research, the aim is to create knowledge of how architectural practice shall integrate data-driven design methods. To assure validity to the study, the aim is deviated to the following objectives:

- Literature study of architectural design exploration, data-driven design methods, and change management with regards to architectural organizations.
- Collect experiences and reflections on data-driven design from the industry.
- Mapping the processes needed when implementing data-driven design methods.

1.3 Research questions

With this research, the aim is to create knowledge of how architectural practice shall integrate data-driven design methods. The integration of data-driven design methods in architectural design enhances the ability to develop more knowledge about the evolving design. The first research questions search answers on how these methods add value to design exploration.

- *How should data-driven design methods be used in order to add value to a design exploration?*

The second research question search answers how data-driven methods should be integrated into current architectural design activities to improve designers' ability to create a better-built environment.

- *How should data-driven design be integrated into the design process to add value for the designers/design team?*

The third research question focuses on architectural organizations' responsibility to create environments where employees can use data-driven design methods in their projects.

- *How shall organizations integrate data-driven methods in their operation?*

1.4 Focus and Limitations

The thesis will focus on the design process from an architect's perspective, specifically in the design phase of a building. To capsize the research questions, specific software connected to data-driven design methods is not studied in detail.

2 METHODOLOGY

The chapter aims to describe applied methods in the study and how it's anchored into the theory of scientific studies.

2.1 Nature of the study

According to Bryman, Bell and Harley (2019), the appropriate research methodology depends on the research problem statement. Due to the nature of the subject, a qualitative research approach will be used to create a holistic understanding of the aim and objectives.

Through systematic combining, a non-linear and non-positivistic approach will be used. Systematic combining is explained by Dubois and Gadde (2014) as an interplay of interrelated elements in research, where the researcher is going back and forth between empirical findings and theory, and the analytic framework with the evolving case. The interplay is accordingly with Figure 2.1.

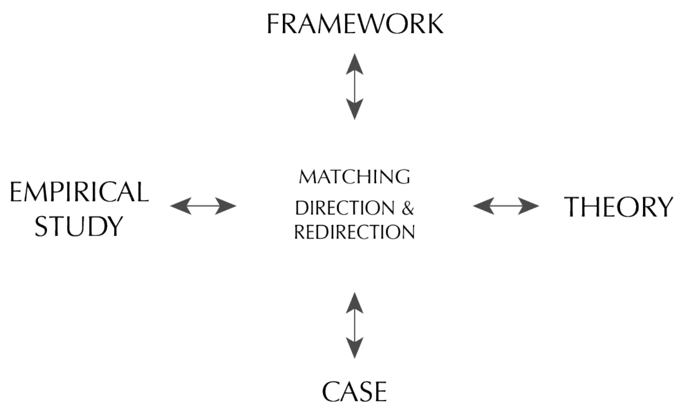

Figure 2.1 Visualization of systematic combining. (Dubois & Gadde, 2002, p. 555)

Empirical data is collected from several sources to form conclusions of the investigated topic. An informative set of empirical data collection originates from professionals with various roles, yet directly associated with the research topic. The study is partly carried out at an architectural company where the researcher has worked for the last three years. Therefore, an autoethnographic research approach will be used, where personal experiences are described and analyzed. To understand a cultural experience, autoethnography uses tenets of autobiography and ethnography (Ellis, et al., 2010).

The researcher has the role of an architect and is newly assigned the position as a digital knowledge developer of the investigated company. The role is shared with one more employee. The task is to enable an organizational environment that can adapt to progressive design methods that add value to the design process.

2.2 Execution and process of the study

Due to the stated nature of the thesis, the content is subdivided depending on the method's characteristics. The used methods are compiled in Figure 2.2 to give an overview of how the study is carried out.

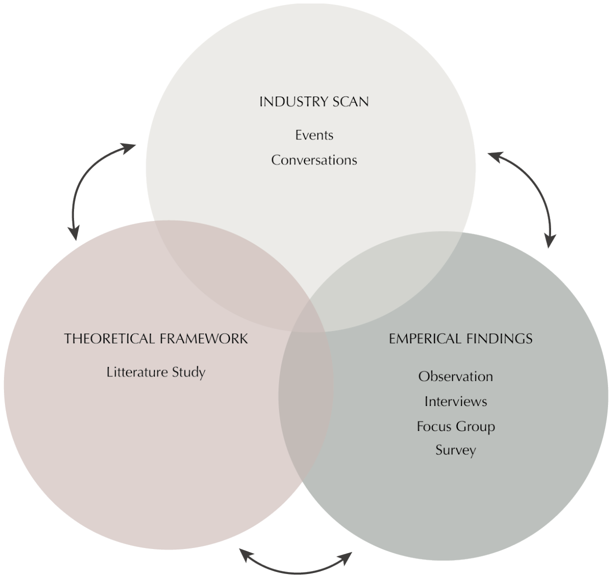

Figure 2.2 Outline of research process. (made by author)

The inspiration for the research came through webinars, conferences, and conversations. Take-aways from these events were reflected, discussed, and projected as topics in internal meetings with key persons. As knowledge from these sources happens iteratively throughout the study, the experiences are summarized by the term, industry scan in Figure 2.2.

The process is an evolving and continuous process where ideas and assumptions from the industry scan influence the research methods: the two lower circles in Figure 2.2. Arising knowledge and input from these are affecting one another through a continues interplay where the research is going back and forth between the three circles in Figure 2.2, consequently leading to an evolving case. Even though the industry scan is not integrated into the research methods, some statements within the analysis and discussion rely on the knowledge possessed through conversations and events in the industry scan.

2.2.1 Literature study

The subject is initiated by a literature study where contexts and workflows of architectural design practice are studied together with theory covering areas related to data-driven design. The literature study proceeds with theory in how organizations should deal with change. The literature study focuses on the architectural design processes and contexts, creative processes, knowledge-intensive processes together with change processes as data-driven design methods are investigated.

The literature study serves as a knowledge background and as a basis for the empirical data collection. Although, the process of reading is iterated throughout the study to complement remaining methods by deepened knowledge and, consequently, give rise to mature reflections.

2.2.2 Observations

Observations of implementations in practice, along with attitudes regarding data-driven design methods, is one of the complementary methods in the empirical findings. The method is oriented towards participant observation in which the author is somewhat attendant. In ethnographic participant observation roles, the researcher can be distinguished based on how well the researcher is integrated with members and social settings (Bell, et al., 2019).

The researcher has, as mentioned in section 2.1 been employed at the company for three years, resulting in that the level of involvement in social settings is high, and a complete participant role is possessed. As a digital developer for less than a year, the researcher has a participant's role as an observer. This role is the same as the complete participant, but members of the social setting are aware of the researcher's status. Therefore, the researcher is somewhere between these two definitions (Bell, et al., 2019).

Due to the position of the digital developer, observations are unstructured classified as most observations occur daily and naturally. Structured observation is conducted when an external company presents its data-driven design product for the employees at the investigated company. The presentation, as well as subsequent discussions, are observed and documented.

Documentation of observations, in the form of field notes, can be classified as mental notes, jotted notes, and complete field notes (Bell, et al., 2019). Mental notes are taken, since physical notes or using a recorder during these observations can make participants aware that they are studied and prohibit the conversation's quality. Complete notes are written down as soon as possible with details of what is observed.

2.2.3 Focus Group

A focus group contributes to the study and consists of nine participants with specific roles in digital development at the company. The researcher acts as a moderator within the group. The moderator's role is to provide fairly unstructured settings while guiding the session to encourage open-minded discussions by views and perspectives among the participants. The focus group offers the researcher the opportunity to study how individuals collectively make sense of conversations with others in the same role (Bell, et al., 2019).

The meeting is scheduled for one and a half hours. The other digital knowledge developer takes sessions during the meeting. These are later sent to everyone in the group. Afterward, are conversations held with every participant to ensure that mutual views are achieved and, also, to absorb more information from the participators.

2.2.4 Interviews

The interviews are of semi-structured character, meaning openness and transparency should characterize more of a conversation (Bell, et al., 2019). Questions are formed, so respondents are allowed to go 'off scope' by personal reflections, as they are following an agenda connected to the target objectives in Section 1.3. Respondents are chosen so that validity is brought to the empirical data regarding digital development.

The semiqualitative interviews have been held with three types of groups based on their role and background. To differentiate between professionals, participating interviewees are categorized according to Table 2.1. Interviews are held one by one, and its questions are differentiated depending on the interview group. The questions are shown in Appendix (I, II, III)

Table 2.1 Participating interviewees.

Interview group	**Description**	**No. of participants**	**Duration** [min]
I	The interviews are carried out with top management at the company	2	30
II	The interviews are carried out with people who now work in the company where the case study is carried out, who earlier had roles working with digital development and to some extent still do.	4	30-60
III	The interviews are carried out with people with various roles and professions in the construction industry to collect attitudes from different actors towards progressive design methods and how architectural firms shall operate regarding progressive design methods.	4	45-90

The structure of Interview group I was, to some extent, organized. Questions were sent and answered in a written manner beforehand and then followed by a discussion based on the answers. Interviewees had, therefore, time to reflect on the questions before the interview took place. Documentation of the following interview was established as field notes to compliment written answers.

For group II, notes are made during and mediately after the meeting and later sent to the participant. The interviews were based on a discussion based on the participant's interests and experiences. In addition, were discussions yet structured towards common questions from the belonging questionnaire.

The interviews for group III was recorded and later transcript. The interviews were based on common questions, but discussions and supplementary questions varied dependent on the interviewee's background and role.

2.2.5 Survey

A survey is carried out with employees at the company to explore attitudes and knowledge of design methods and digital development. It is also used to understand the perceived view of how the company works with digital development, both historically and today. 22 of 90 employees at the company participated. The survey acts as a complement to the observations made at the company.

Surveys are defined by Check and Schutt (2012, p. 159) as “the collection of information from a sample of individuals through their responses to questions.” The survey contains a mixed strategy of qualitative and quantitative research methods, by asking both open-ended questions, closed questions, and numerical rated questions, emphasizing the qualitative part. The question asked in the survey are according to Appendix IV.

Since the survey is anonymous, the mixed approach is chosen to put the questions in a context with who is answering the question and, to some extent, understand the knowledge this person possesses in specific programs or methods. Every theme of the questionaries' is ended with an open question to allow participants to describe their thoughts further. Important in the post-processing of quantitative results is to remain qualitative and avoid general formulations.

2.3 Analysis and interpretation

Notes and recordings from interviews, observations, and the focus group are summarized after every occasion together with exact quotes, freely translated from Swedish to English. Summaries are then sorted into specific themes according to the principle of thematic analysis, see Figure 2.3.

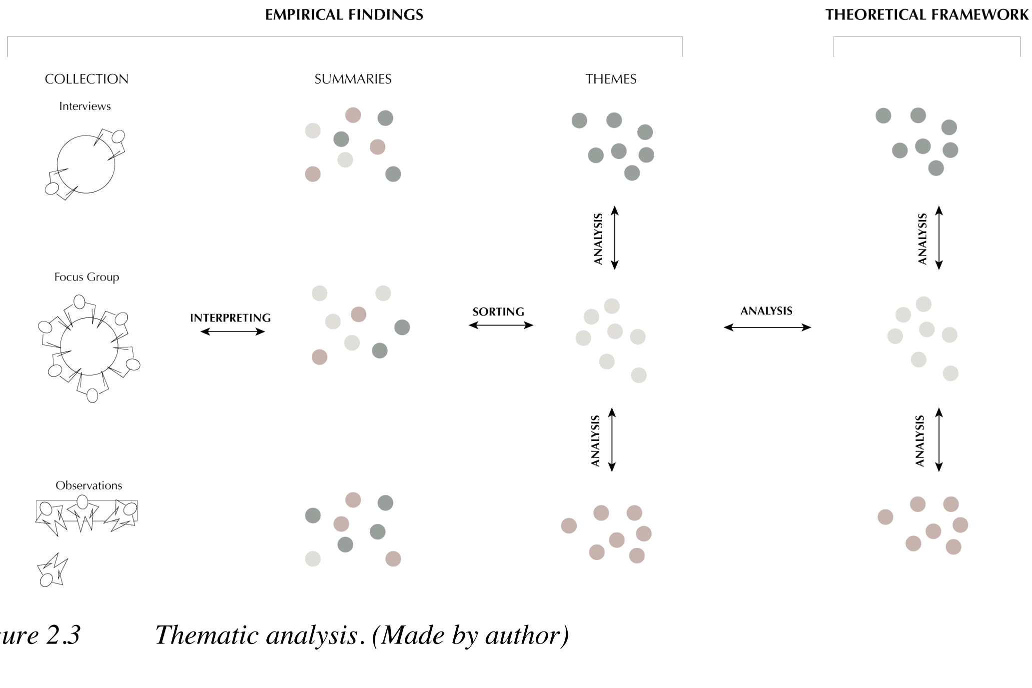

Figure 2.3 Thematic analysis. (Made by author)

According to Bell, et al. (2019), a theme is a category identified by the researcher related to the topic of investigation. Themes applied in this scientific study builds on transcriptions and field notes. Furthermore, themes provide a base of theoretical understanding of how the data can contribute to the literature via connections between the two. One of the most common criteria to consider empirical findings as themes is to find patterns of repetition. To be considered a theme of value, it must be relevant to the topic of investigation.

2.4 Ethical perspectives

The four major ethical principles in conducting research are avoidance of harm, obtaining informed consent, protecting privacy through confidentiality, and preventing deception (Bell, et al., 2019).

To show respect for privacy and anonymity, all involved are informed of the background to the research topic, how information is processed, and how each individual is presented. No one was harmed during this research, and all participators have freely chosen to participate in the study. Answers are anonymous and presented as collective answers among participants from the company. External participants are presented with the professional role and work-related tasks. Reconciliation is made for qualitative methods to minimize misinterpretations and increase validity.

Due to the autoethnographic approach, should others implicated by the researcher's personal experiences be allowed to respond to how they are presented in the text (Ellis, et al., 2010). The answers from the company's participant in the empirical finding are therefor approved by the CEO and the top management before the research is presented.

2.5 Validity

To gain credibility, evaluation, and comparison of possible interviewees' contributions to the research were investigated before interviews were made. To create dissemination of information, the interviewees were selected with different roles, experiences, and knowledge. Since empirical findings are based on how the researcher interprets the material, direct quotes from the interviews were transcribed to avoid misinterpretations. In addition, follow-up questions were asked to create a more in-depth understanding (Bell, et al., 2019).

3 THEORETICAL FRAMEWORK

The theoretical framework is initiated with a brief description of the processes and contexts in which architectural design exploration operates. This serves as a base for the following part, which describes data-driven design methods and processes. The last part of the theoretical framework describes organizations and change management.

3.1 Architectural design exploration

Architectural design is a world of divergent solutions, and our built surroundings are the result of design processes were some paths where chosen and many more were ignored. The emerging design exploration is a complex process where the finished result is heavily dependent on external factors as the personal skills and knowledge of each designer in the design team (Pressman, 2012).

3.1.1 Architectural design- a knowledge intensive product

Firms whose service or product is characterized by complex and unique tasks, where solutions are tailored toward specific needs and demands by individuals of the firm, are often described as knowledge-intensive (Ejler, et al., 2011). Any product made by a knowledge-intensive firm heavily relies on the knowledge and cognitive skills of its personnel (Alvesson, 2004). Architectural design is based on the knowledge from several actors connected to the design process with different areas of expertise (Hamilton & Watkins, 2009).

Knowledge can be seen as a possession and resource of the human mind. Knowledge, in this context, is often described by a hierarchic pyramid, shown in Figure 3.1. Data is explained as symbols that do not have any value on its own. Information is data that is processed and organized. When individuals confer meaning to data and information, by previous understanding, subjective experiences and perceptions reach the level of knowledge (Newell, et al., 2009). Wisdom, which is the next level in the hierarchic pyramid, deals with values (Ackoff, 1989).

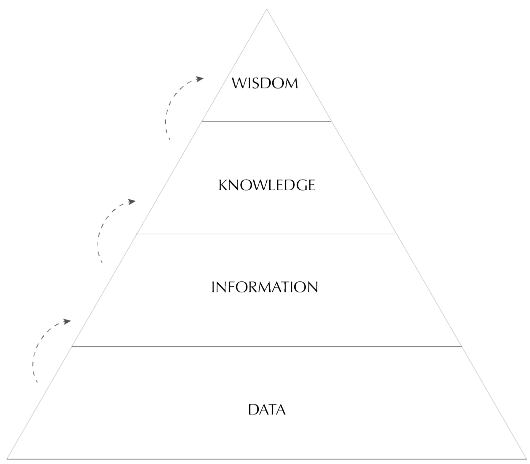

Figure 3.1 The hierarchical relationship between data, information, knowledge and wisdom. Information answer the question who, what, when, where and how many. Knowledge answer to the question of how. (Ackoff, 1989). (Adapted by author)

Knowledge can be separated between tacit and explicit knowledge. Where explicit knowledge can easily be formulated, expressed, and shared among others through interaction. Tacit refers to knowledge based on personal experiences that are hard to express for others (Newell, et al., 2009). Intuition is heavily dependent on tacit knowledge (Alvesson, 2004). To further distinguish knowledge, typologies of knowledge can be defined according to Table 3.1.

Table 3.1 Knowledge Typologies (Canary & McPhee, 2011)

Typology	Description
EMBRAINED	Knowledge dependent on conceptual skills and cognitive abilities.
EMBODIED	Action-oriented knowledge. Dependent on practical, intimate knowledge of situations.
ENCULTURED	Knowledge grounded in shared understandings through cultural meaning systems.
EMBEDDED	Knowledge which resides in system rules and routines. Is grounded in relations among system roles, technologies and procedures.
ENCODED	Information conveyed by signs and symbols.

A strong knowledge base and shared collective understanding are essential for knowledge-intensive firms (Alvesson, 2004). Organizational knowledge has its base in encoded, encultured, and embedded knowledge. For knowledge to be shared by the members of an organization, interactions need to be enabled. (Canary & McPhee, 2011)

3.1.2 The creative, iterative design process

There are many ways in how to define creativity. However, the critical factor is to apply knowledge and skills together with imagination to produce original outcomes that connect to desired values and goals (Padget, 2012). It is not very likely that creative practitioners hit their goals on their first try. “A creative practice is a practice of failure as much as it is a practice of creating” (Sharp, et al., 2019, p. 57). Therefore, a creative process is often described as iterative, where the designer learns from failures in a cyclical era, where failure sheds light on the next version of an idea, which ultimately leads to the desired outcome.

An iterative process lets its actors explore and take risks but, at the same time, move more carefully in the creative process (Sharp, et al., 2019). A simplified version of the constituent parts of an iterative process is presented in Figure 3.2.

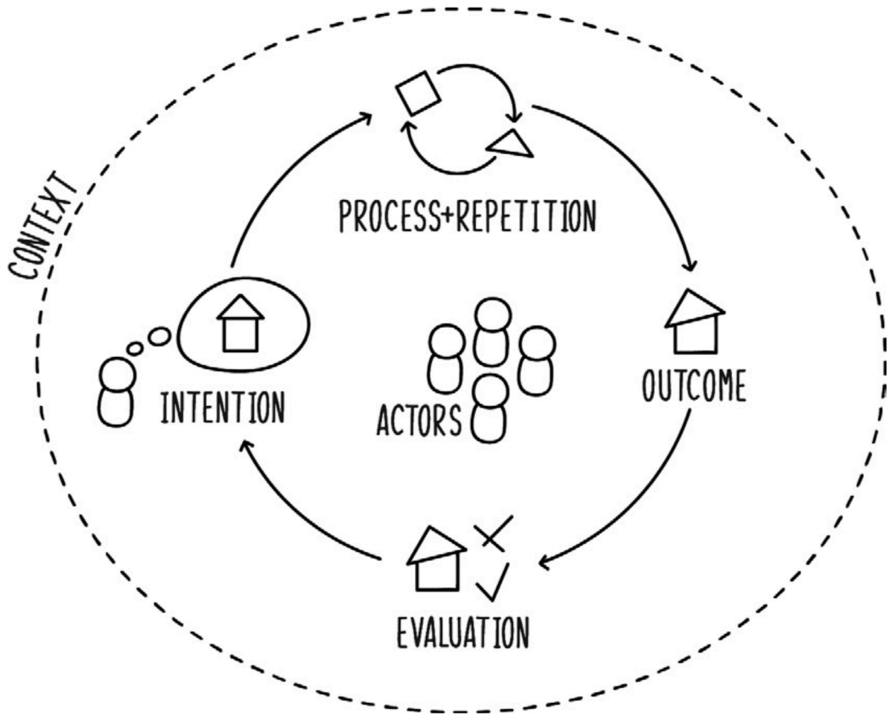

Figure 3.2 The cyclic process of iteration (Sharp, et al., 2019, p. 49).

Intention, process, evaluation, and outcome drive an iterative process and answers to the questions why, how, and what. The cyclic process takes place within a context that makes sense of the challenges and is carried out by actors who enact and interact with the creation. They are directly or indirectly involved in the iterative process, where the later could be stakeholders, company executives, and society (Sharp, et al., 2019).

3.1.3 Ingredients of architecture

Architectural design is a complex process where multiple users and stakeholder needs should be included, together with regulation, budget, and performance criteria, to name a few of the involved components which the design should be tailored towards. To create a valid response to these needs, scientific and social matters are required (Bachman, 2019).

In
Figure 3.3, a summary of how some of the contextual demands, together with the architect's attributes, impact the emerging process of a design.

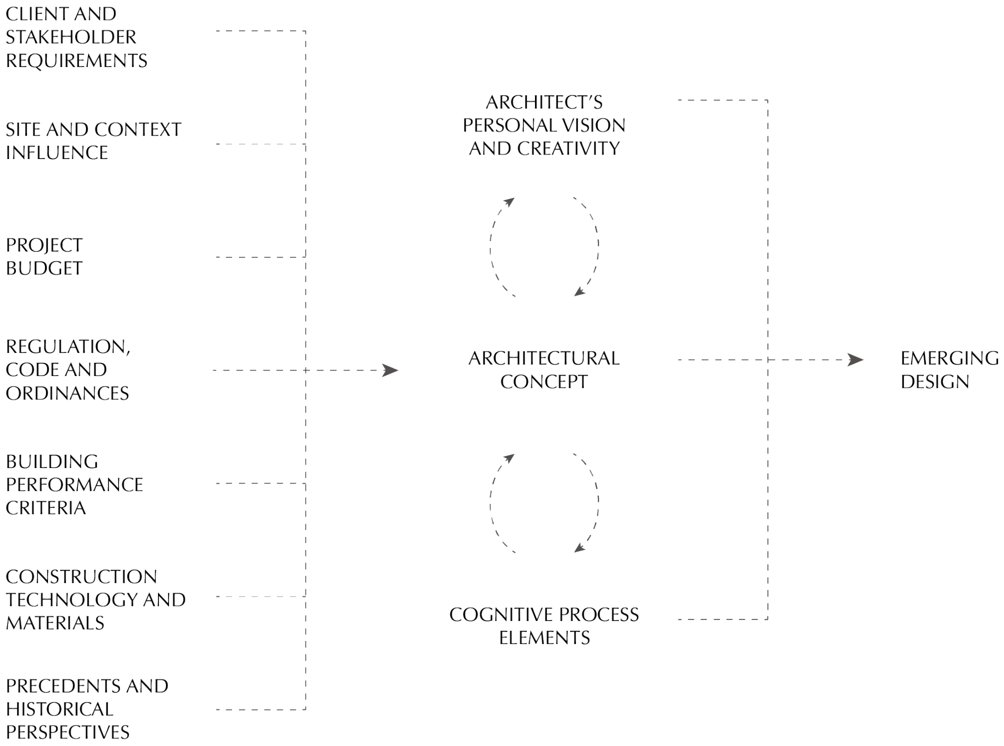

Figure 3.3 *The diagram is a simplified accounting of the ingredients of architectural design. Interaction between any of the "cognitive process elements" and more tangible "components" is, in actuality, complex, idiosyncratic and continues. (Pressman, 2012, p. 24) (Adapted by author)*

A concept, which is central in Figure 3.3, integrates the external conditions such as the project program, site, and other factors to a formative idea of the building. Creating a concept is vital to architectural design in the emerging process since it serves as the basis for the decision-making process. The concept is greatly influenced by the architect's knowledge, personal vision, creativity, and the cognitive procedure of processing information (Pressman, 2012).

3.1.4 The building design process

Except for the external conditions, together with the designer's personal creative and cognitive process, the design exploration is heavily influenced by the building design process. Architects and other participants in the design exploration all have the building process to relate to. Circumstances in each project, such as site, program, and clients, are unique for each project, and therefore there is no exact description of the building project process. But there are generalizations of common procedures which, to some extent, exists in each project. They are presented by Eringstam & Sandahl (2018) in

Figure 3.4.

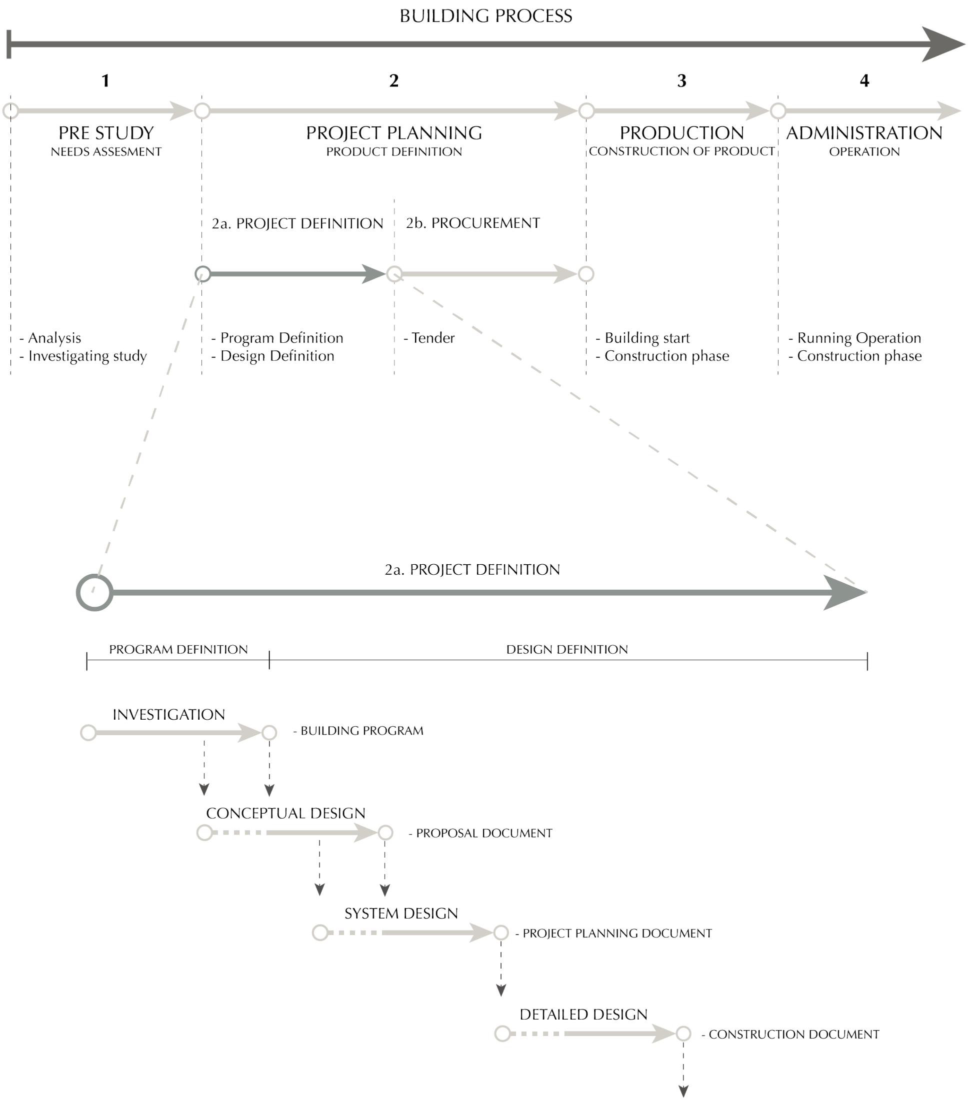

Figure 3.4 *Different stages of a construction project, with focus on the project planning definition stages and its documentation. (Eringstam & Sandahl, 2018, pp. 24-25) (Adapted by author)*

The building process is, in general, initiated by a pre-study. This phase involves identifying the needs and conditions of the future project and whether it is economically defensible to continue with the project or not. The subsequent step is the development of the building's design. At this stage are architects and other necessary consultants commonly assigned the task of defining the project so that it meets the regulated requirements of the building and the wishes and needs of the developer and client (Eringstam & Sandahl, 2018).

The parts included in the project definition are described in 2a according to

Figure 3.4 and illustrate the steps in which the design is developed and what type of documentation is produced in connection to each step (Eringstam & Sandahl, 2018). This process is often accordingly with a waterfall process, a linear system where each step needs to be completed before the next phase starts (Smith, et al., 2014).

Waterfall processes strive to be predictive, where fixed frameworks for scopes, cost, and schedules are determined as early on as possible in the process. Focus on keeping these frameworks solid is a significant concern, and changes are handled carefully. The waterfall process partly has its origin in the construction industry because of the sectors high interest in avoiding late changes, since these often result in cost- and/or time overruns (Smith, et al., 2014).

3.2 Data-driven design exploration

Data-driven design is a process where data is given a central role in the development of a design. The design methodology focuses more on developing an object than on the finished object (Bier & Knight, 2014). Continuous feedback on the design provides the designer with data to evaluate and determine how the design process shall proceed (Bier & Knight, 2014). Carpo (2014, p. 173) describe how "These methods are enabling designers to make and break more chairs, beams or roofs in a few minutes on a screen than a traditional craftsman made and broke in a lifetime."

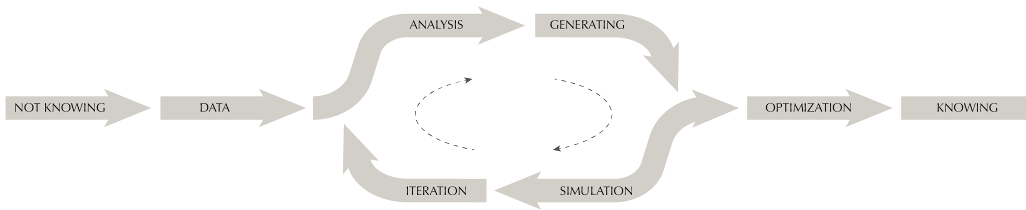

Figure 3.5 Iterative decision knowing flow diagram. Design professionals move from not knowing to knowing by means of an iterative feedback loop (Deutsch, 2017) (Adapted by author).

Through the continuous loop of feedback from data-driven design methods, shown in Figure 3.5, designers can react to the data and, through evaluation of the result, improve their knowledge of the design. The term data-driven tends to imply that the design outcome is primarily driven by the data. However, data's role is to inform intuition and thereby, knowledge so the best available decisions on how the design shall proceed through the iteration can be made (Deutsch, 2017).

The following chapters will briefly cover the involved parts of the suggested data-driven iterative design process, presented in Figure 3.5.

3.2.1 Collection and integration of data

The first step in the iterative data-driven design process is to collect, select, and integrate data in a digital representation of the model. In the following sequences, data management methodologies will be presented so that responsible use of data is ensured.

3.2.1.1 Collection of data

Data can connect what we can do with what we want to do. Based on our intentions of the design, data helps us predict the outcomes of each alternative (Spetzler, et al., 2016). Data has always played an important role in architecture and with increased computational power, more data is available for designers to include in the design. However, more data does not mean that it contributes to design. To just use data without thoughtfulness can have devastating results (Agi, et al., 2020).

In order to ensure that the data is credible and serve as evidence, several sources should be included. Evidence is explained by Barend's et al. (2014) to be facts, information or data that in turn support or disputes an assumption, claim or hypothesis. In order to have an evidence-based design exploration, four areas, shown in Table 3.2, should be considered.

Table 3.2 Evidence based practice (Barends, et al., 2014).

Evidence	Description
SCIENTIFIC	Information that can be collected from scientific reports and studies. The reliability of the information needs to be ensured with a qualified assessment of the credibility of the source.
STAKEHOLDER	This can be briefly seen as the views and views that can be obtained from anyone affected by a decision. This can be a customer of a service or a future tenant in a planned building. Often the priorities of the group vary, and the result is not always unanimous.
EXPERIENTIAL	Information contained in experience, accumulated the proof of how the outcome tends to be for different scenarios. This must not be confused with personal opinions, but is aimed at excellence obtained by repetitively performing a task
ORGANIZATIONAL	This type of proof refers to information available in companies or organizations. This can include, for example, costs or statistics, but also customer satisfaction.

One common method to collect data are measurements of various kinds, such as climate data, noise data, transport statistics, to name a few. This information is often contained in large databases, some available to the public; meanwhile, some are not. As data becomes more accessible and the power of data increases, there are great potentials for its usage since more information is available and can be united and/or evaluated to one another (Agi, et al., 2020).

Data can also be collected by opinions, dialogues, and observations of citizens. In order to use the results from such methods, the gathered data should be sorted and broken down in smaller variables and be presented in diagrams and other visual tables (Agi, et al., 2020). Data can also be collected by sensors. This works for environmental phenomena such as air quality, noise, climate data, to mention a few. It can also be used to collect human behavior data collected from swipe cards and mobile devices (Deutsch, 2015).

Several data sources exist within the construction industry, such as data from material suppliers, data from experiments of specific components, or data attached to regulations. Stakeholders and organizations often possess data or measurable standards that can be used as data (Agi, et al., 2020).

Architectural design operates in the uncertainty of the future, determining which data and information matters and which does not is there for a constant challenge (Spetzler, et al., 2016). To ensure that data contributes to the intended design, a clear structure of the required data is needed. This work can be simplified by sorting questions connected to the design goal, based on their urgency or other critical aspects to reach the design goal (Wilde, 2018). All projects are different and have specific requirements in each design, so it is up to each design/project team to define what is meaningful for each particular situation and project (Deutsch, 2015).

3.2.1.2 Systems for integration of data

The way data is integrated into the design process and integrated between actors in the design team is a significant concern. A high-performance building can only be achieved if it contains integrated systems, integrated teams, and integrated information (Fischer, et al., 2017).

In the last few decades, BIM (Building Information Modelling) has created a paradigm shift for design teams in the construction industry. BIM can act as a database for the design team where all relevant information of a building and its components are integrated into a digital 3D representation of the building. The goal of BIM is to create a structure for how information is shared between all actors in the design process. The 3D representation of the building can then be used by facility management and future users of a building (Aksamija, 2016).

Thus, the possibilities of BIM as a database; the majority of BIM users still use it primarily for documentation creation, visualization, clash detection, and coordination (Deutsch, 2019). To fully exploit benefits from data-driven methods and computation capacity, multidisciplinary input of data is required.

For the different actors in the design team to work effectively, an integrated chain of information needs to be established, where there are clear definitions of specification and systems (Ramsgaard Thomsen, et al., 2020). The integrated information enables a high level of accuracy in the building design. To start immediately with BIM in the design exploration, without having a plan for how data should be exchanged and integrated, can severely constraint a design teams' ability to produce a successful project (Hardin & McCool, 2015).

Hardin and McCool (2015) claim that BIM projects' success depends on how well BIM is communicated among the actors in the project team. Integrated Project Delivery (IPD), is one effort in establishing more integrated teams, systems, and information. The concept of IPD is to establish design goals and make decisions as early as possible in the design process to minimize costly changes in a later stage, see Figure 3.6.

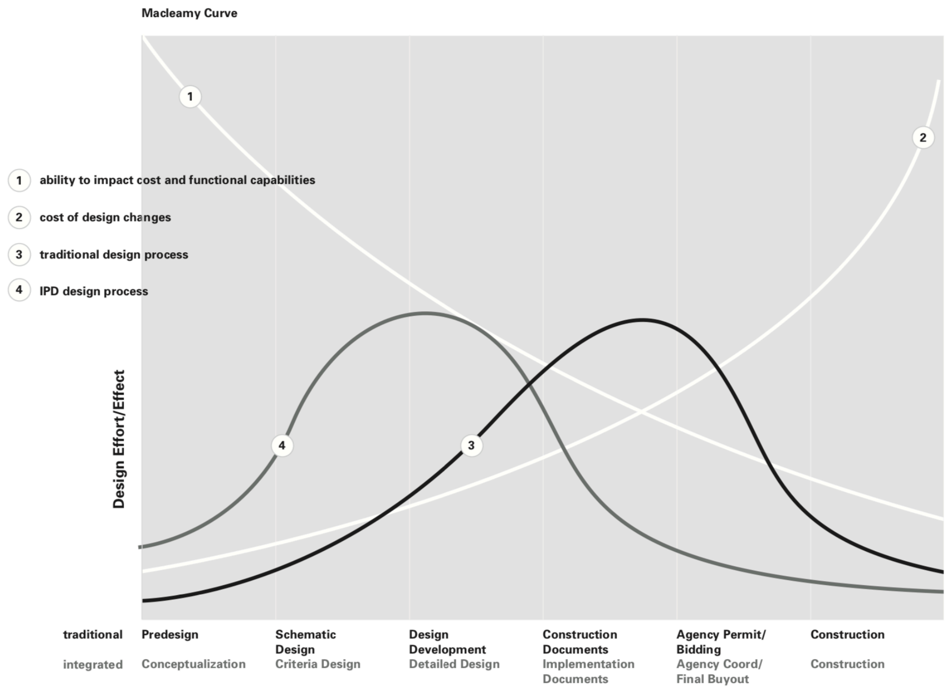

Figure 3.6 The "MacLeamy Curve" illustrates the concept of making design decisions earlier in the project when opportunity to influence positive outcomes is maximized and the cost of changes minimized, especially as regards the designer and design consultant roles (The American Institute of Architects, 2007).

The IPD method relies on the early contributions and expertise of involved stakeholders and participants in the design process. BIM offers excellent advantages to IPD thanks to its ability to store data. BIM does also provide a more integrated and interactive approach for the design team to be collaborative within (The American Institute of Architects, 2007).

3.2.2 Analysis

Analysis in architecture is used to predict or evaluate data of building design so that it can ultimately reach its goals. Analysis can be done by physical testing, calculations, expert judgments, and stakeholder assessment (Wilde, 2018). The many aspects and values to consider in architecture means there is a high complexity while analyzing. Data analysis enables a rational analysis of a building by including all available data using customized digital analysis tools (Spetzler, et al., 2016). In Figure 3.7 and Figure 3.8 are data from several evidential sources analyzed and put in relation to one another.

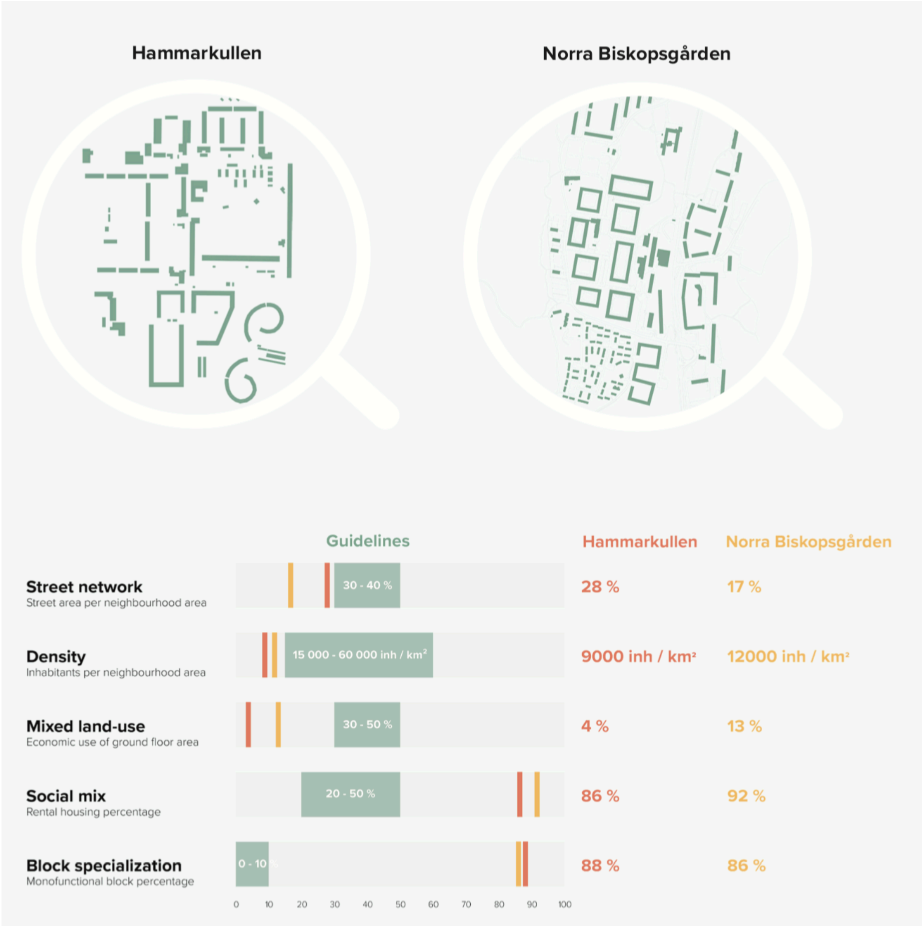

Figure 3.7. Measured data are benchmarked towards guidelines in city planning theory. This analysis creates an evident baseline upon which design decisions for urban development can be made (Forsemalm & Göransson, 2019).

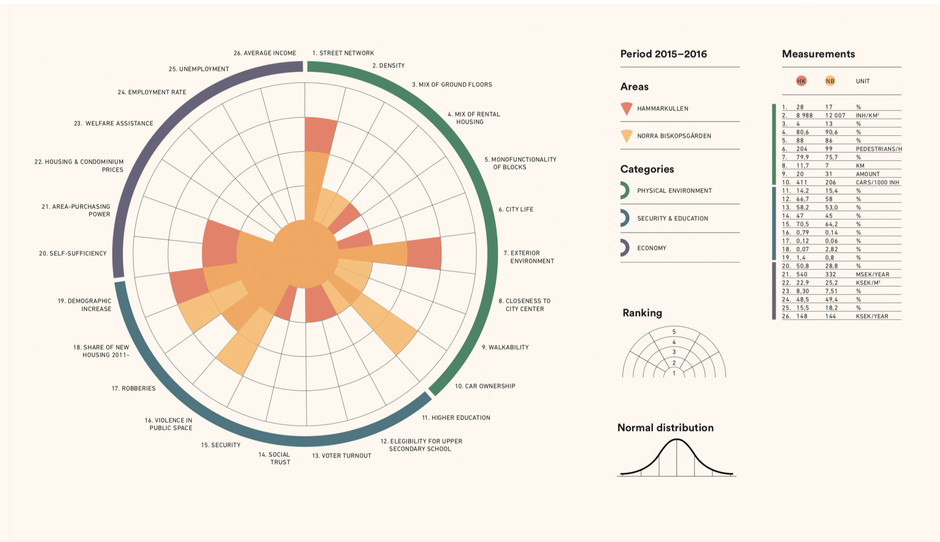

Figure 3.8 UQI, (Urban Quality Index) is an analysis tool that measures the qualities of an urban area and include data in three thematic topics: physical environment, safety and education, and economy. The included data is from municipality sources, police and measured observations. The data is benchmarked towards other areas in the same geographic settings (in this case Gothenburg) (Forsemalm & Göransson, 2019).

The analysis tools can be used for various reasons when figuring out how a design will perform and handle certain conditions and situations. It can also be used to understand how the design will affect its occupants and its surroundings. Commonly used digital analysis for building performance are wind factor analysis, energy analysis, sound analysis, transports analysis, movement analysis, and material analysis. In Table 3.3, Wilde (2018, p. 10) describes some of the reasons for analyzing building performance.

Table 3.3 Reasons for analysis of building performance (Wilde, 2018).

Reason	Description
FACTOR SCREENING	To find out which factors have most impact on the performance.
OPTIMIZATION	To find the parameter values and system configurations that result in the sought performance.
CONFIRMATION	To verify that a system performs as is expected.
DISCOVERY	To establish the performance of new systems, combinations and so on.
ROBUSTNESS	To study how system performance changes in adverse conditions.

There are several regulations and standards in the construction industry, which data can be compared and analyzed towards, such as noise regulation or light regulations. However, no instrument can measure and perceive light in the same way as the human eye. Therefore, measurement and data shall not be used for more than an estimation and shall be evaluated critically together with experienced values (Alenius, 2016). The same is for sound and noise analysis, where regulations put great effort into regulating the maximum sound level. Note that it's not just the sound level itself that impacts the human, but also the characteristics of the sound (Agi, et al., 2020).

3.2.3 Generative design

Generative design is a cyclic process that iteratively searches for optimal solutions based on multiple objectives connected to the design goals. The process relies on algorithms that describe the definition of a design idea. Within the boundaries of the goal, all possible solutions are then generated and available for the designer to evaluate (Aksöz, 2020). Nagy, et al. (2017) describes how the software extends the human abilities of design exploration, enabling more in-depth exploration of the design because of its ability to process information in an incomparable speed to the human mind.

Generative design is often related to building performance and can only find solutions within the limitations of setting up design variables and quantitative goals. These processes open new doors for the obsession of numbers and performance, which requires the ability to frame the right questions from the very beginning (Aksöz, 2020). However, for an architectural designer, there are no definite formulations or rational rules to define a design problem. The task is to find the best solution to multiple objectives, both quantitative and qualitative, which often conflict with one another. The generative design shall therefore be approached as a tool, which helps to design the conceptual framework of the design goals (Aksöz, 2020)

Various generative design solutions and their abilities to reach set design goals can be seen in Figure 3.9.

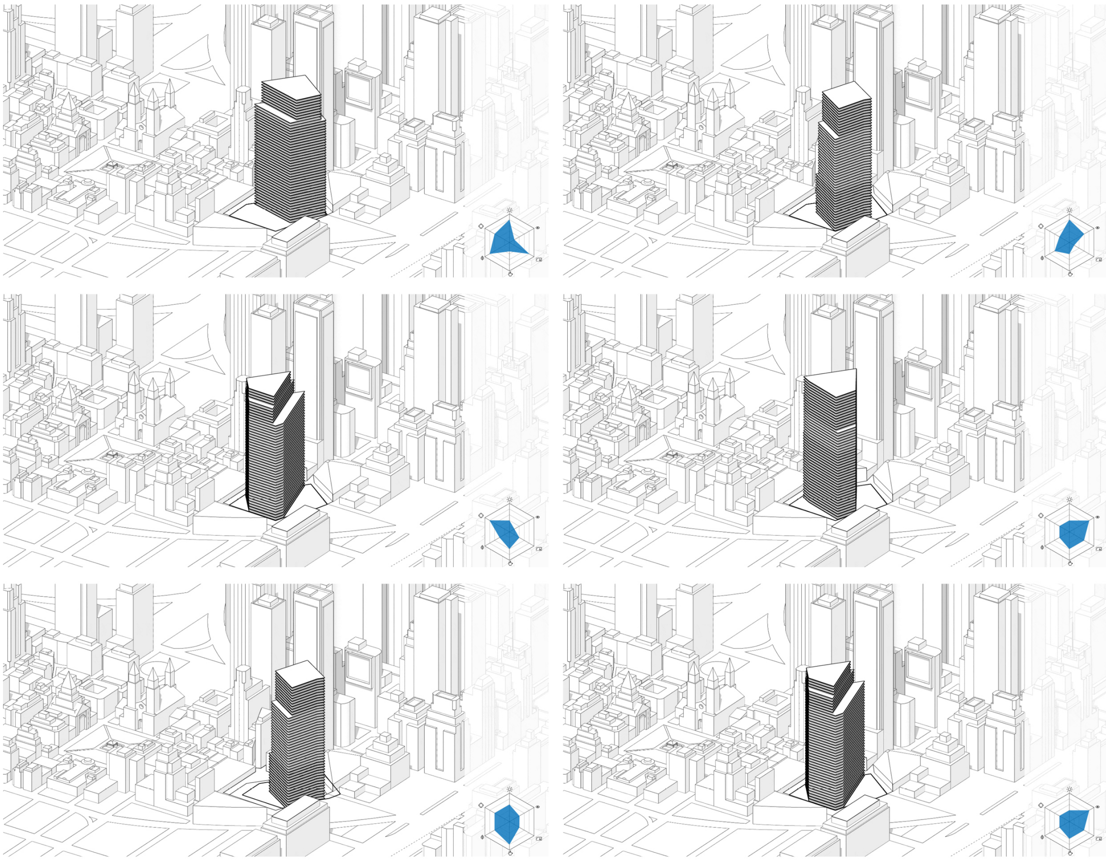

Figure 3.9 Generative design suggestions based on input values and output values are chosen to be amount of area and volume (Smith, 2019)

3.2.4 Simulations

Computational simulations enable an analysis of certain real-world phenomena in a digitally created virtual world. Moreover, goal-directed experimentation and experience collection are enabled during controlled conditions using dynamic models that show how structures or behaviors vary over time (Mittal, et al., 2017).

Simulation is something that architects have turned to, hoping to create more sustainable and functional buildings and more compelling buildings thanks to the visual benefits that simulation brings (Goldstein & Khan, 2017). The simulation tools aim to facilitate continuous valuable feedback between design goals and building performance. As Knuth (1968, p. 30) describes, *"We often fail to realize how little we know about a thing until we attempt to simulate it on a computer."* In **Fel! Ogiltig**

självreferens i bokmärke., some of the benefits of simulation are provided by Mittal, et al. (2017).

Table 3.4 Benefits of simulation (Mittal, et al., 2017, p. 7)

EXPLORATION	Learners can explore domains that would otherwise be too time-consuming, expensive or dangerous.
FOCUS	Facilitate the removal of complexity and detail from a model, focusing only on the aspects of the model that are most relevant to the learning.
VISUALIZATION	Make it easier to visualize dynamic or complex behavior
MOTIVATION	they motivate by providing context and engagement, encourage active involvement, and arise interest.
CONTROL	learners can control timing and detail, they can explore and experiment, hypothesize and test.
PRACTICE	to address misconceptions and allow learners to learn from their mistakes.

Simulation tools are based on scientific fields that indirectly influence the industry, such as computational science, mathematics, material science, physics and biophysics, human behavior, and environmental science. (Hensen & Lamberts, 2011). The digital simulation tools enable designer multiple forms of evaluation, such as daylight, structural integrity, thermodynamics, and uncontrollable variables such as weather and human behavior. The latter two, because of a wide range of behavioral patterns and environmental conditions, can be tested (Goldstein & Khan, 2017). In Figure 3.10 a wind simulation is represented.

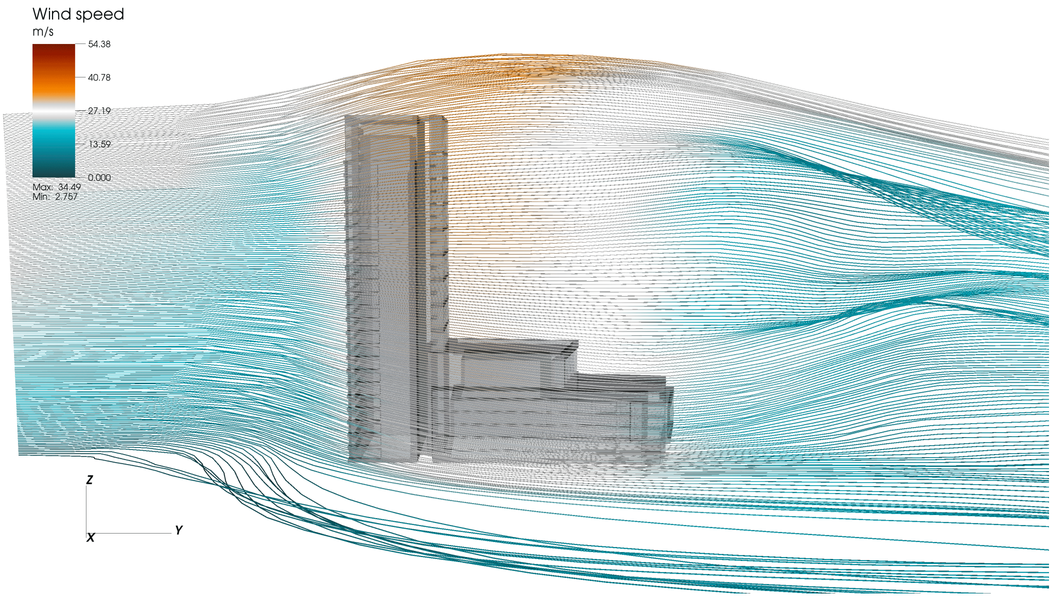

Figure 3.10 Wind simulation. (Ingrid Cloud, 2019)

There have been multiple tools developed to model specific aspects of a building. It is essential to regard buildings as complex dynamic systems, where one system is not separated for another. For most simulation tools, the analysis is separated from others and studied in isolation because of a lack of integrated systems. Although simulation strives to mimic worldly scenarios, it can never be guaranteed that all aspects of a building's complexity are taken into account (Goldstein & Khan, 2017).

Even though simulation tools have existed on the market for decades, architectural practice finds it hard to integrate them into their current design activities. In Brix Purup and Petersen's (2020) investigation of problems with the integration of Building Performance Simulation tools (BPS Tools), they found eight significant issues that should be adjusted for architectural firms to adapt to these tools, shown in Table 3.5.

Table 3.5. Qualities needed in order to integrate Building Performance Simulation tools (Brix Purup & Petersen, 2020).

INDEPENDENT OF DESIGN PROCESS	The BPS tool must support typical architectural design activities, i.e. support what architects actually do when they design – not dictate certain processes or workflows.
FAST AND IMBEDDED	Use geometrical data from architectural computational models consistent of different level of detail and make the BPS tool a plug-in to the computational software, there should be no manual export of data.
INDEPENDENT OF GEOMETRICAL SHAPE	No need for simplifying the architectural expression of the computational model to enable BPS.
INDEPENDENT OF COMPUTATIONAL DESIGN TOOLS	The BPS tool should (at least) work with the most used computational tools in the industry.
DIFFERENTIATED INPUT INTERFACE	Make the tool usable to non-experts who want to apply BPS by making simple interfaces for setting up simulation parameters (e.g. by using templates or wizards) but make all input variables accessible in another interface for the advanced user.
FAST VERSUS PRECISE SIMULATIONS	The BPS tool for the early design stage should build on feasible tradeoffs between precision and simulation speed.
INTUITIVE VISUALIZATION OF SIMULATION RESULTS	Visualizations of simulation results should 1) be presented in a way that non-expert immediately can decode it 2) allow experts to assess the output in detail, and 3) support stakeholder collaboration.
AUTO-GENERATE DOCUMENTATION	An export function that generates reports containing input/output data for documentation purposes.

3.2.5 Iteration of design

The data-driven design process suggested by Deutsch (2017) in Figure 3.5, is analysis, generation, and simulation continuing in an iterative loop until there is an outcome ready to optimize towards a finished design. In each design, iteration is direct feedback presented to the design team, upon which they can evaluate and base decisions upon. Evaluation is, as explained in chapter 3.1.2 *The creative, iterative design* process*,* as one of the driving forces in an iterative process (Sharp, et al., 2019).

3.2.5.1 Evaluation and decision-making

More than often, an iterative process leads to an outcome, not reflecting what was expected. Through evaluation of the failure, the practitioner gains experience and knowledge. The insight from evaluation helps the practitioner make sense of current challenges and influence decisions for how the process shall proceed (Sharp, et al., 2019).

To make informed decisions in the evaluation, decisions should be based on a combination of critical thinking and the best available evidence described in chapter 0. Critical thinking refers to the process where logic and careful reasoning through reflection, analysis, and evaluation of relevant evidence identify and define problems, connections, and competing arguments (Barends, et al., 2014). Through the evaluative process, knowledge is extent, and reasoned judgments and conclusions can be made (DiYanni, 2015). Critical thinking embrace creativity. When critical thinking is trying to make sense of a problem, creativity is trying to find its solutions (Padget, 2012).

Unique and complex problems, which are the reality of architecture, often bring difficulties in assessing quality (Alvesson, 2004). The human mind is not wired to handle unique and complex problems in an uncertain world without rationalizing and satisfying the decision (Spetzler, et al., 2016). To make qualitative decisions, six elements should, according to Spetzler, et al. (2016), be included, shown in **Fel! Ogiltig självreferens i bokmärke.**.

Table 3.6 Elements involved in qualitative decisions

APPROPRIATE FRAME	Specify the problem or opportunity we are tackling, including what is to be decided.
CREATIVE ALTERNATIVES	Alternatives define what we can do
RELEVANT AND RELIABLE INFORMATION	Information captures what we know and believe, but can't control
CLEAR VALUES AND TRADEOFFS	What we want and hope to achieve.
SOUND REASONING	Reasoning helps us understand what we should do, creating clarity a of intention
COMMITMENT TO ACTION	To have real decision, we must be able to act upon it.

Making a qualitative decision is not the same as having a qualitative outcome. It is possible to control the decision, but not the result. The possibility to create a qualitative outcome does, however, increase when making qualitative decisions. Therefore most possible effort needs to be put in the decision-making process. In the face of uncertainty, should the alternative, based on current information and analysis, which have the best chance of delivering value, be chosen. (Spetzler, et al., 2016)

Over the last two centuries, the dominant way to base architectural design decisions has been by intuition, which has tended to be based on the imagination of the future and knowledge with roots from the past and the present (Harrison, 2016). The human mind has the potential to moral imagine how decisions impact lives and societies (Friedman & Hendry, 2019).

With the development of computation and technology, it is possible to eliminate paths that don't lead anywhere and support one's intuition in what direction the design process shall proceed (Deutsch, 2017). Data and information have always been an integrated part of architecture. "Without information, the design would operate in a vacuum, and there would be no basis for decision-making other than personal opinion on how something looks and feels" (Bachman, 2019, p. 32).

Variations of decision-making criteria are shown in Figure 3.*11*. If used right, data can back up the decisions which otherwise would have been based on more subjective grounds. Clients exposed to credible data showing positive outcomes will be more likely to engage (Hamilton & Watkins, 2009). When exploring the design through data, architects are in the position not just to explore and improve their knowledge; they can also influence the understanding of other decision-makers in the project (Deutsch, 2015).

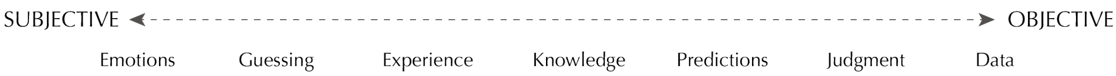

Figure 3.11 A spectrum for decision making criteria (Deutsch, 2015)

Visualizing and communicating the results from information-rich design exploration is crucial for everyone in the design team to create a mutual understanding of driving factors in the design proposal(Agi, et al., 2020). When direct feedback from analysis and simulation, the digital model reaches everyone, more innovative and creative design solutions will be made, at the same time as stronger and better interdisciplinary teams are created (Ramsgaard Thomsen, et al., 2020).

3.2.5.2 Dynamic models

Uncertainties and change will always be part of a design process, resulting in multiple iterations. Models should, therefore, not be created by manual methods but should be based on parametric processes that enable dynamic workflows (Scheurer & Stehling, 2020). Parametric design is based on specific sets of rules and constraints consisting of different parameters, allowing the designer to define the entire system behind how a design is developed. The parameters consist of algorithms, data volumes, or numbers. Based on these rules and constraints, properties such as geometry, numbers, shape, and size can be controlled (Aksamija, 2016).

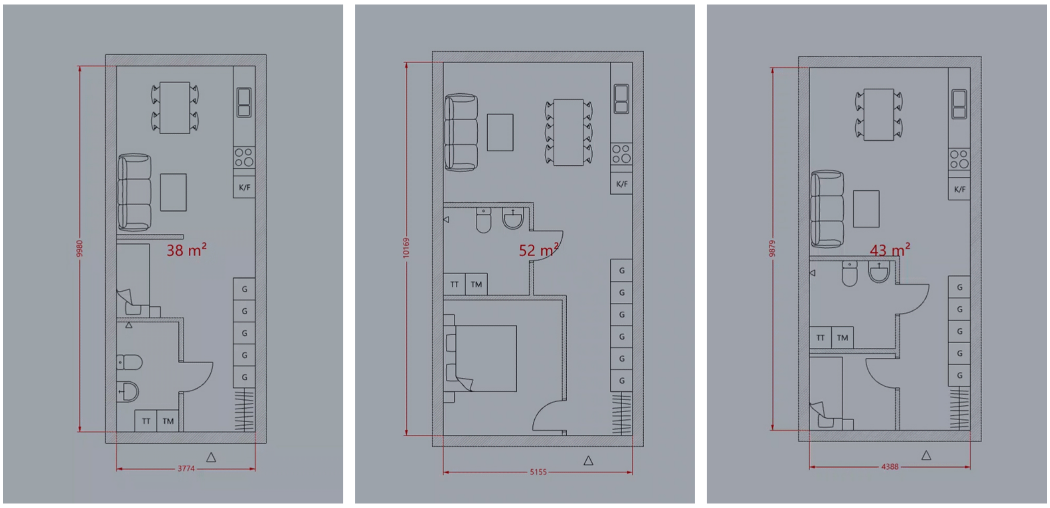

Figure 3.12. Dynamic parametric model, where the plan layout automatically adapts to the changing length and width of the room. (Finch 3D, 2020)

Parametric models are more time-consuming in its creation, but it offers many advantages for the designer. Firstly, instead of manually creating multiple object type variations, the designer can change the critical parameter or parameters to create different object versions. Second, if the model is well-structured, the parameters enable the designer to quickly adapt and modify the model's features while change is needed. Since a series of operations create the model, the designer can easily make changes without recreating the entire model for each design iteration. The third and the most essential feature, according to Nagy, et al. (2017), is how a parametric approach lets the designer, through parametric systemization, explore design solutions more dynamically and profoundly than what's possible in traditional design methods.

The parametric models need to consist of structured rules that untangle and prioritize dependencies; this makes the parametric model more reliable and accurate. The high degree of systematization creates the possibility of a direct feedback loop between the computer and the human mind (Scheurer & Stehling, 2020). In BIM models, do all objects contain several parametric. With parametric controlling tools, it is possible to control the parameters without changing them by manual methods.

Graphical programming tools are mainly used in the systematization of parametric design; thus, it extends the designers' ability to control the design. Parametric programming allows the building to be defined programmatically and modified interactive, which minimizes the number of repetitive tasks. The visual programming environment is integrated with the computational design tool. These tools create a favorable environment for the explorative design process and the evaluative design tools and processes (Goldstein & Khan, 2017).

Establishing a parametric model from very early, can be very challenging and restricting, since exploration only can occur between the boundaries of selected variables. To have more flexibility, many architects use 3D models for sketching without any data connected to it (Aksöz, 2020).

3.2.5.3 Flexible design process

For architecture practice to gain from data-driven iterative design processes, processes that are flexible enough to deal with changing conditions are needed. (Ramsgaard Thomsen, et al., 2020). The usage of data through analysis and simulation in the design process is not a new phenomenon. In traditional linear design processes, these are used at set stages, often by other consultants than architects, and usually when it is too late for changes to be made. This has significant implications for the effective and iterative design process (Knippers, et al., 2020).

Exploration of design is often mistaken for conventional problem solving, and the structure of the design process forces designers to follow a linear, so-called waterfall process. Making decisions early in the design process can have devastating consequences since it can complicate later stages where more information is available and force adjustments in the design that go against the ambitions for the project (Ramsgaard Thomsen, et al., 2020).

Scheurer and Steling (2020) consider an agile design process needed to gain from data-driven design methods. As shown in Figure 3.13, an agile design process enables the design team to stay flexible and adapt to changing parameter values (Scheurer & Stehling, 2020).

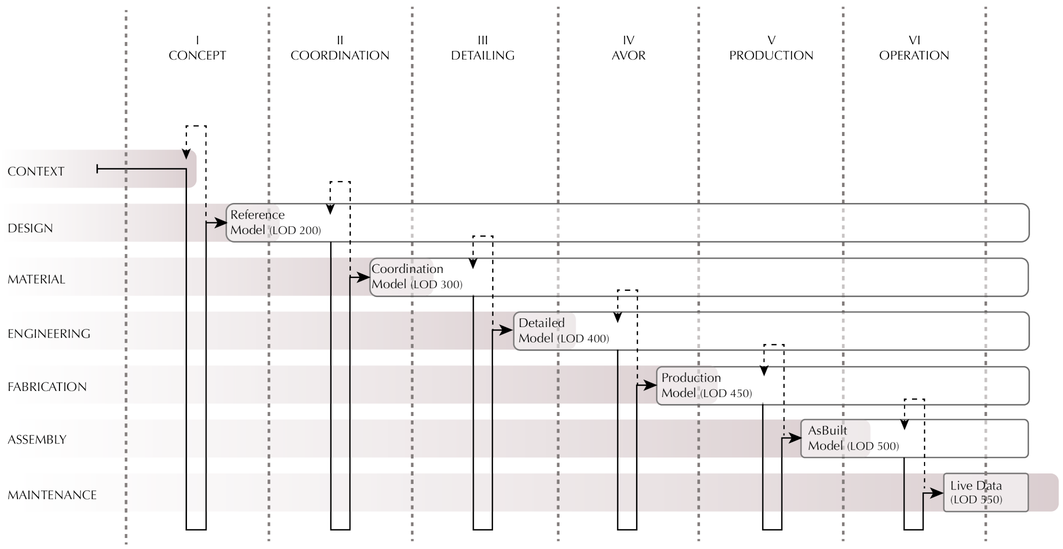

Figure 3.13. Agile Design process model. The diagram shows a planning process through different stages in time (from left to right) and varying abstraction levels of detail (LOD). (Scheurer & Stehling, 2020, p. 46) (Adapted by author)

For data-driven design methods to be used effectively, no more than the essential information should be integrated into the model. (Aksöz, 2020) The Level of Detail, known as LOD, is an effort to create a common language for the amount of information applied to a model and its elements (Daniotti, et al., 2020). There are several steps and different levels which are distinguished accordingly with Table 3.7

Table 3.7 The Level of detail (Aksamija, 2016, p. 90)

LOD 100	Overall massing includes indictive area, height, volume, location and orientation. May be modelled in three dimensions or represented by other data. Elements doesn't contain any details whatsoever.
LOD 200	Elements are modelled as generalized elements with approximate placement, size, geometry and quantities.
LOD 300	Elements are specific modelled; this means that they correct in terms of placement, size, geometry and quantities.
LOD 400	Elements are specific modelled; this means that they correct in terms of placement, size, geometry and quantities. They also contain information about fabrication, assembly and detailing information.
LOD 500	Elements are modelled as constructed assemblies with actual placement, size, geometry and quantities. They also contain information about assembly, fabrication and detailing information.

3.3 Integrate change

According to Kotter (2012), both present and future changes require organizations that are welcoming change. The following chapters will cover organizational structures' impact on change and strategies that improves the ability to be aware of change and approaches that simplify the process to integrate change.

3.3.1 Organizational impact on change

To have the capacity to adapt to change quickly, organizations need to make sense of their business context (PMI, 2013). Organizational structure impacts how organizations shall handle change, foster innovation, and exchange ideas of development. It is impossible to describe all organizational models, but there are mainly three organizational structures in which organizations can be placed in between. (Kerzner, 2017). They are presented in Figure 3.14.

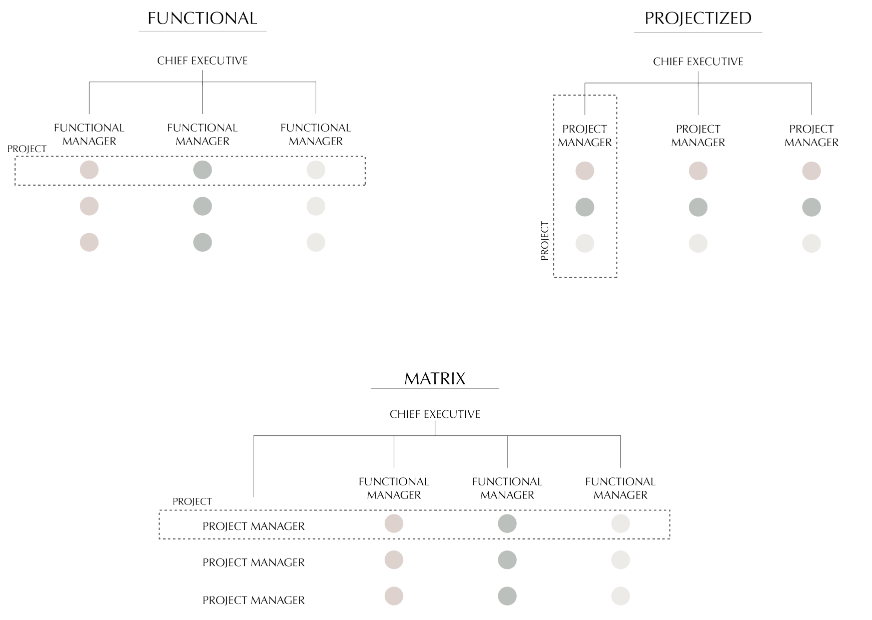

Figure 3.14. The different colors represent individuals with different area of expertise. Inspired by Kerzner (2017, pp. 91-98) and PMI (2013, pp. 21-27). (made by author)

The most traditional organizational structure is the *functional organization*, where particular *functions* are defining the organizational design. Each group is divided into departments where the members have concentrated technical expertise. The structure creates good possibilities for strong communication between the functional manager and its members. Standards, procedures, and knowledge between the members can therefor easily be shared. Communication and coordination between different functions are, however, complex and decision-making is often a slow process since no functional manager is responsible for the entity of the project or product, why the chief executive needs to be involved. The traditional model is well suited for mass-production since each project flow through the functional departments in set stages (Kerzner, 2017).

The *projectized organization* structure is the opposite of the traditional model (PMI, 2013). The organization is heavily dependent on projects, and members with different expertise knowledge are tightly connected through the project. In a project-based organization is communication and knowledge exchange between members with the same technical expertise complex, since the projects separate them. This results in difficulties in creating standard methods and may result in repeated efforts and solutions within the same organization (Kerzner, 2017).

In the *matrix structure,* do communication flow in two directions: both within the projects and between the functional groups. In this way, it is possible to easily communicate both within and between the projects. This leads to that the obstacles connected to functional and projectized organizational structures are minimized. Since communication is happening in two directions, problems with dual messages for the organization's members may occur. Dependent on how much influence the project manager versus the functional manager has, it gets similar advantages and disadvantages as the functional structure versus the projectized structure have (Kerzner, 2017).

For organizations that want to foster change, should the number of obstacles that slowdowns the process of adopting changes be minimized. The organization should be flexible, and the leadership should be spread to more people. Management's role is essential in providing an organizational environment where change is welcome (Aksamija, 2016). In other words, an organization that wants to be able to react to changing conditions should be agile (Kotter, 2012; PMI, 2013; Aksamija, 2016; Holbeche, 2018).

An agile organization adapts to its environment just as a living organism, see Figure 3.15, by self-regulating to internal and external changes, and if it doesn't it dies. An agile organization is non-linear and multi interacting between its members, where individuals are free to act and respond to their environment, based on simple rulesets and models (Holbeche, 2018).

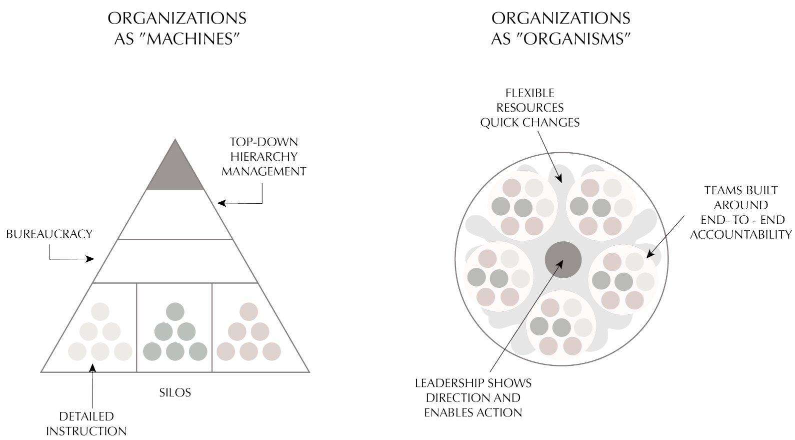

Figure 3.15. Rather than organization as machine, the agile organization is a living organism (Aghina, et al., 2018)

Agile organizations help delivering more value to customers and enable possibilities to achieve better business outcomes. By empowering employees to seek direct contact with stakeholders, they can take charge of the end-to-end product. This creates a sense of ownership and accountability in the teams simultaneously as it saves time and fosters innovation. The teams must be enabled to share ideas frequently to ensure alignment and solve problems. Agile organization work in rapid cycles of thinking, where the leadership shows the direction (Aghina, et al., 2018).

It is essential to find a balance between the organizational model, its culture, and its underlying values. Based on a firm's values, there are differences in how it operates. There are mainly three different operation categories, where all architectural firms fit in, shown in Table 3.8. They may operate in between the different categories. (Aksamija, 2016)

Table 3.8. Operation of architectural firm

STRONG DELIVERY	Firms are organized for efficiency and rely on standard solutions. They tend to have a strong formal structure and stable working environment; they are often specialized in specific building types. The design processes and production are standardized.
STRONG SERVICE	They are organized for service and highly dynamic environment that allows changes to managerial structure. This allows the firm to respond to different needs of the client and they typically cower a wider range of building types.
STRONG IDEA	The firm tend to focus primarily on conceptual processes and design thinking, but the organizational structure is flexible. They provide unique results and standard solutions are rarely considered since client typically employ these types of firms for unique projects.

The goals and motives for how organizations shall implement change must reflect the characteristics of the firm. To specify the firm's identity and its core values is necessary for how the practice can handle change within these boundaries. The motives and goals must, however, be established so that they can survive changing market conditions. (Aksamija, 2016)

3.3.2 Predict changing conditions

To be aware of change, organizations need to adopt change into their strategic planning, which should be an iterative, emergent, and continually evolving process (PMI, 2013). Technological changes are not static and will continue to develop, most certainly at a higher speed than today. For organizations to implement change, they need to be alert and aware of changing conditions. Research is defined as the "systematic investigation and creation of new knowledge and applications" By research, organizations will have the ability to adapt to innovative methods and techniques (Aksamija, 2016). Focusing on innovation is not limited to the specific research topic. It has also been shown to improve the potential of already known tools and processes (Knippers, et al., 2020).

There are several models of operation for research. The right solution depends on what motives an organization has with research and how it correlates with the organizational structure and size, and how dedicated it is to innovation. In Figure 3.16, different models of research are shown. *Internal research practice* is closely influenced by the organization's design practice and is funded by the firm or driven and funded by the client. Researchers are employees of the firm, and the research results are implemented immediately in practice (Aksamija, 2016).
When research is integrated into the design process, researchers can engage immediately with the technique or method under investigation. Following the methods and procedures during the design process will empower the researcher with expertise from practice, industry, and academia (Sheil, et al., 2020).

External research practice relies on the involvement of external partners. The correlation of the research and the design practice varies and depends on the impact the architectural practice has on the research agenda. The structure and execution of research are also strongly dependent on how the research is implemented in the architectural practice. *Hybrid research models* are a mix of internal and external research models. One common strategy by firms is to develop a separate nonprofit organization that partly relies on funding from the organization and partly from other sources (Aksamija, 2016).

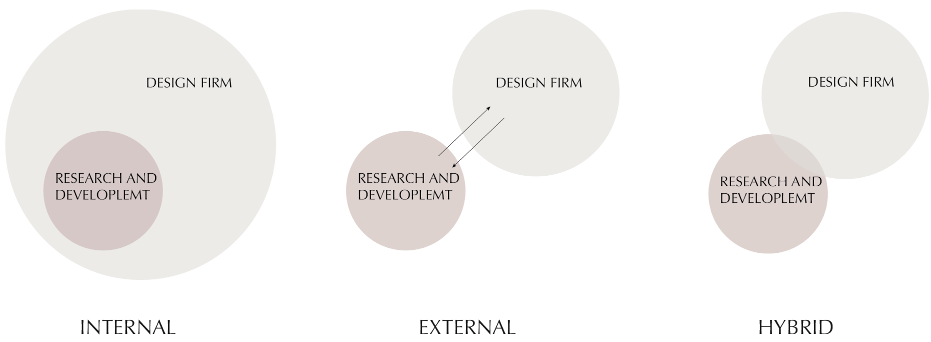

Figure 3.16. Models of operation for research and design (Aksamija, 2016, p. 176).

Knippers et al. (2020) emphasize how design research is the core competence and potential needed to solve problems with the construction industry’s impact on society and the environment. But innovation through research can’t happen solely between a singular discipline or institutes. It will require close collaboration and intersections where knowledge and values are directly confronted with one another. The integration of social science and humanities will also be needed in research.

Research in organizations can be challenging together with the realities architectural firms face, such as client requirements, budgets, schedules, risk, and liability. These activities can be very costly if there are no operational models and relationships between research, design practice, and business performance. A careful and systematic approach to establish research is needed to reduce risks. It is also necessary to evaluate the advantages of the respective disadvantages of keeping internal people looking at research or if it is more beneficial to use outsourcing and partners (Aksamija, 2016).

3.3.3 Integrate Change

To benefit from changing conditions, there needs to be systems and structures for how change should be integrated in the operation (Aksamija, 2016). According to Kotter (2012), organizations that manage to incorporate change successfully do so in a multistep process that creates motivation for all involved. Kotter and Cohen (2012), proposes an eight-step approach where each step empowers change, shown in Table 3.9.

Table 3.9. Eight-step process in change management.

STEP	ACTION	NEW BEHAVIOR
1.	INCREASE URGENCY	People start telling each other, "Let's go, we need to change things!"
2.	BUILD THE GUIDING TEAM	A group powerful enough to guide a big change is formed and they start to work together well.
3.	GET THE VISION RIGHT	The guiding team develops the right vision and strategy for the change effort.
4.	COMMUNICATE FOR BUY IN	People begin to buy into the change, and this shows in their behavior.
5.	EMPOWER ACTION	More people feel able to act, and do act, on the vision.
6.	CREATE SHORT TERM WINS	Momentum builds as people try to fulfill the vision, while fewer and fewer resist change.
7.	DON'T LET UP	People make wave after wave of changes until the vision is fulfilled
8.	MAKE CHANGE STICK	New and winning behavior continues despite the pull of tradition, turnover of change leaders, etc.

The process of change begins with creating a sense of urgency among the relevant people. The next step is to assemble a team, who has the potential to make successful changes thanks to their knowledge, contacts and the reputation and credibility others have for them. The groups should be enabled with high confidence from management with emotional commitment in return. (Kotter & Cohen, 2012)

The group's first goal is to develop clear and straightforward visions and strategies for what they want to achieve. To implement changes, visions and strategies must be continuously communicated. The goal of this is to create understanding and create commitment from other employees and to release energy from those critical of the change. Repetition is vital, and in general, it is better to explain with symbols than with words (Kotter & Cohen, 2012).

For the implementation of data-driven methods in an organization, Wilde (2018) suggests a data strategy for the company where the first step is for the organization to educate its workforce to minimize performance gaps while communicating the benefits of data in practice. Then the firm should decide how to keep track of design and performance data. Finally, they should find ways to share their data.

Kotter and Cohen (2012) explain how the key priority for employees to be able to act is to remove obstacles that are in the way for action. Organizations need to empower people to act in order to make change happening. However, this process cannot be translated directly into handing out more power. Instead, there should be clear frameworks for which employees can relate their work to. One common problem people do when trying to achieve their vision is to do too much at once. This usually means they find themself in a situation hopelessly bogged down with the result that they give up too soon. Therefore, short-term wins are crucial. After the first wins, people continuously choose what to tackle next, to "create wave after wave of change until the vision is reality".

For change leaders to make change stick, they need to nurture a new culture; the new culture develops through consistency successful action over a sufficient period of time. Appropriate emotions, new employee orientation, and events that engage emotions can make a big difference. Otherwise, the already executed work can be blown away by the traditional workflows (Kotter & Cohen, 2012). Strategy, structure, culture, and systems are central issues in implementing change, but the core obstacle is s to change people's behavior. To present the reasons for change, two ways are suggested by Kotter & Cohen (2012), shown in Table 3.10.

Table 3.10. Ways to present reason for change

	SEE - FEEL – CHANGE		ANALYSIS – THINK – CHANGE
1.	HELP PEOPLE SEE Compelling, eye-catching, dramatic situations are created to help others visualize problems, solutions, or progress. *As a result:*	1.	GIVE PEOPLE ANALYSIS Information is gathered and analyzed, reports are written, and presentations are made about problems, solutions, or progress *As a result:*
2.	SEEING SOMETHING NEW HITS THE EMOTIONS The visualizations provide useful ideas that hit people at a deeper level than surface thinking. They evoke a visceral response that reduces emotions that block change and enhances those that support it.	2.	DATA AND ANALYSIS INFLUENCE HOW WE THINK. The information and analysis change people's thinking. Ideas inconsistent with the needed change are dropped or modified.
3.	EMOTIONALLY CHARGED IDEAS CHANGE BEHAVIOR OR REINFORCE CHANGED BEHAVIOR.	3.	NEW THOUGHTS CHANGE BEHAVIOR OR REINFORCE CHANGED BEHAVIOR.

The typical way is to use the second one since it is more competently and more comfortable than the first one. But the change of behavior happens mostly by speaking to the feelings of people. Analysis and data gathering are not unimportant; sometimes, you have to show numbers to open the door that enables people to see. Both thinking and feelings are essential for what people do, but the heart of change lies in emotions. Therefore the real possibilities for transformation of behavior lie in visualizing the problem, solution, or progress and use the *see-feel-change* methods (Kotter & Cohen, 2012)

3.3.4 Contribute to change

In a study conducted by Agi et al. (2020), most interviewees, who all were city planners or architects, considered it essential that architects should take responsibility in developing design tools. This to avoid the possibility of being guided in a certain direction and risk that restrictions are incorporated into the tools available on the market. If the architects develop tools themselves, they will learn what is possible and what is not, at the same time, as it is possible to have complete control over their design process.

They will also gain more knowledge through collaboration with other professionals in the construction industry and have a more significant opportunity to make more accurate judgments on the results received from their analysis. However, there is an obstacle that architects generally lack programming knowledge (Agi, et al., 2020). The variants of software environments available concern Clausen et al., (2020) because of how it risks undermining common workflows and collaboration.

4 EMPIRICAL FINDINGS

The chapter is subdivided by means of the shape of a cone, starting wide by presenting the participating actors and narrowing down to reflections on the research objectives.

4.1 Participants in the empirical collection

The empirical collection originates from internal and external actors. The first relates to an architectural firm that participates through observations, interviews, an employee survey, and a focus group. The group of external actors participates through interviews and a held presentation.

4.1.1 Architectural firm

The architectural practice started in 2001 in Gothenburg and is, according to Innovationsföretagen (2019), among the top 30 architectural offices in Sweden regarding turnover for the year of 2018. Internal numbers for 2019 show that they are in the top 20. The company consists of 100 employees based in Malmö, Göteborg, and Stockholm. The last three years have meant significant changes in the number of employees with an increase of 40 percent. The company is working with housing projects in all scales, infrastructure projects, city planning, commercial properties, and interior projects. They have projects in all stages of the design process and strive towards keeping the projects from conceptual design to detailed design.

Employees in the project-based organization are architectural designers, interior designers, and construction engineers. Three years ago, an attempt to integrate more daily leadership lead to a re-organization, where the role of "*Team Leaders"* was established. They are responsible for the daily leadership were incorporated into the organization. This role is often connected to personal development. They are also responsible for the communication between top management and the individuals in each team. This role is not related to the projects, and the teams consist of individuals with different experiences and different functions. The projects consist of people from different teams. A simplified visualization of the organization can be seen in Figure 4.1.

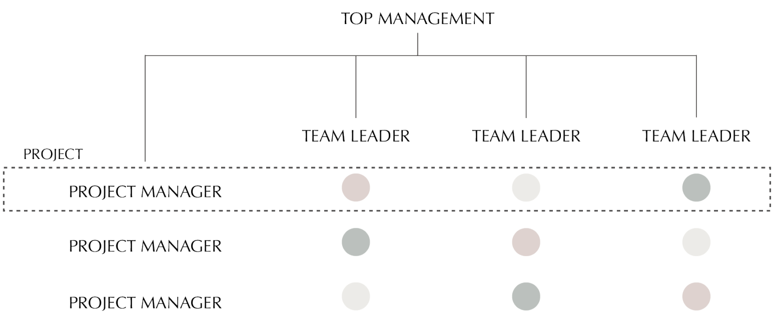

Figure 4.1 Simplified organizational chart of the architectural firm. The different colors represent employees with different roles. (made by author)

(Interview Group I)

TOP MANAGEMENT AT THE COMPANY

The two remaining founding partners are interviewed and are, together with the top management, deciding what strategic moves the company shall proceed with. They are responsible for recruitment. To some extent, they contribute to all projects of the company and responsible for the projects the company delivers. Their profiles can be seen in Table 4.1.

Table 4.1. Interview Group I

Role	Description
Founding Partner	The interviewee is the head of design of the company. He has worked in various projects and stages and has more than 20 years of experience in architecture.
Founding Partner	He has more than 30 years of experience in different architecture projects and design stages.

(Interview Group II)

EXPERIENCED EMPLOYEES IN DIGITAL DEVELOPMENT

The interviewees are four experienced employees who all, to some extent, have been part of digital progress in architectural or engineering companies. The description of their roles and experience are presented in Table 4.2.

Table 4.2. Interview Group II

Role	Description
Project Manager (Engineer)	The interviewee has at previous employments been in charge of developments of BIM usage. Today the interviewee does not want to be the one driving the work forward, but he wants to contribute with his knowledge and pedagogic.
Project Leader (Engineer)	The interviewee has worked at the company for many years and has been responsible for the knowledge development of CAD and to some extent also with BIM. Today the interviewee is a member of the quality group and the program council.
Model manager (Engineer)	The interviewee has long experience in the construction industry and has previously driven the development of BIM at an engineering firm he previously worked at. He is interested in be part of the development.
Model manager (Engineer)	The interviewee has created the base models which the company use for their design. He has a great interest in new tools and methods and is also a member of the program council.

(Focus Group)

MODEL MANAGERS AT THE COMPANY

The model managers are responsible for the data and information in the projects. Frequent work-related tasks are to organize models, handle questions of multidisciplinary sharing, and deliveries to clients. They are people with knowledge in Building Information Modelling and are the ones closest to the employees' competence in digital tools in the projects where Building Information Modelling is used. Their profiles can be seen in Figure 4.2.

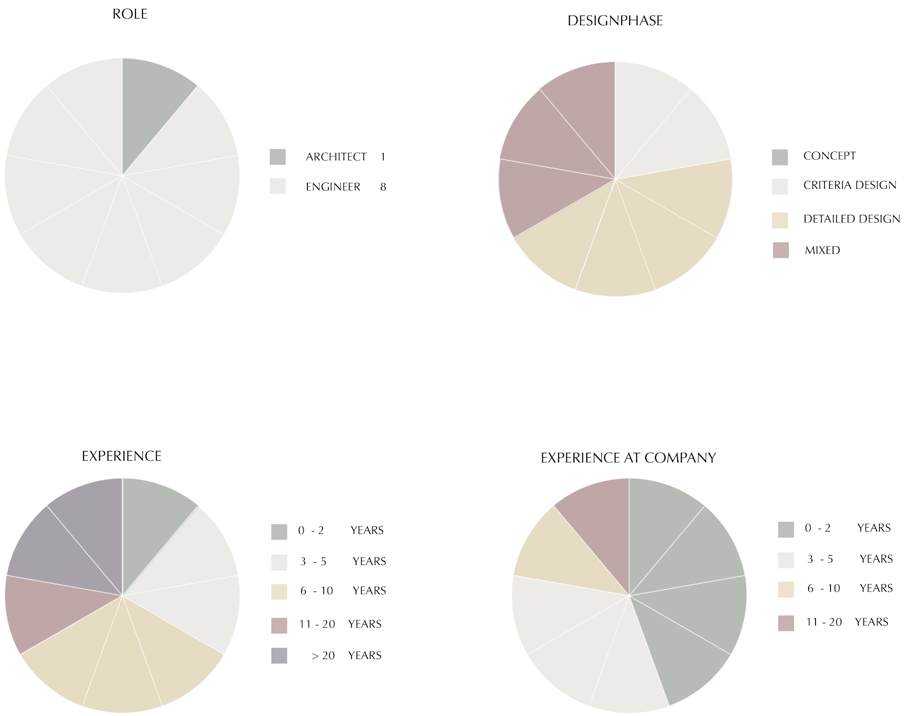

Figure 4.2. Distribution of role, type project, overall experience as well as experience at current company for the Model Managers.

(Survey)

EMPLOYEES

A survey was sent out to all employees, where 22 out of 90 employees who are working in projects every day answered. The distribution of professional roles is shown in Figure 4.3, where the left diagram represents the survey. The right diagram represents the total distribution of positions between employees who work daily in projects. Thus, roles related to the administrative, project planning, or similar, were not asked to participate in the survey.

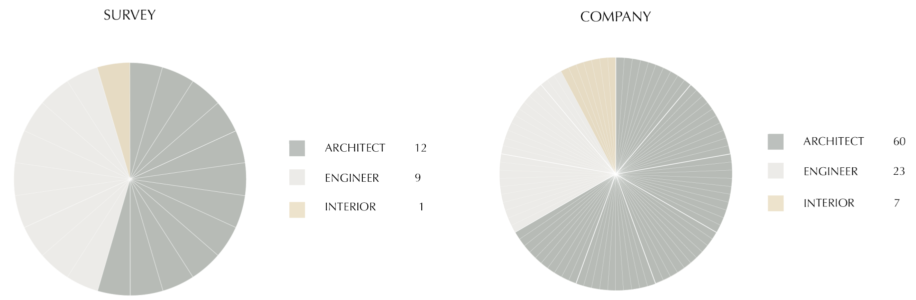

Figure 4.3. The roles of the employees participating in the survey in comparison with role distribution at the company.

4.1.2 Industry Experience

(Interview Group III)

PEOPLE WITH EXPERIENCE IN DATA-DRIVEN DESIGN METHODS

People with knowledge in data-driven design methods, both through academic experience and work-related experience, are interviewed. Their profiles are described according to Table 4.3.

Table 4.3. Interview Group III

Role	**Description**
PHD Student (Architect + Engineer)	The interviewee is a researcher within Architecture and Engineering. The research area is within material informed sculptural modelling and form optimization, a field from where he has industry knowledge whilst working for Architecture and Engineering companies in the United Kingdom.
Lecturer (Architect)	The interviewee is a lecturer within Digital Architecture and also a part-time architect, who works most in the early stages of design. Expert in 3D printing and imagery. The interviewee has experience in various internationally recognized architectural companies.
Computational Designers (Architect/Engineer)	The interviewees are founders of a company who provide scripts for parametric and generative design, mainly in Grasshopper and Dynamo. They also offers parametric solutions for handling of big data within the BIM process.
Strategic Consultant	The interviewee is working at a consultant company who tailor digital BIM, product design and lifecycle solutions to help their partners work smarter.

(Seminar/Presentation)

COMPANY PROVIDING GENERATIVE DESIGN EXPLORATION AND ANALYSIS

The investigated company invited a consultant working for a company that provides a cloud-based generative design product to hold a seminar regarding generative design and simulation at the investigated firm. After the presentation was a spontaneous seminar/questionary held by the employees and the consultant. The company provide a product that lets its users explore multiple design propositions of volumes and/or plan layouts based on selected parameters and provides a detailed analysis for each proposal. The invited firm spoke about their product as a 'design and decision support tool' that develops ideas with respect to the building's site.

The presenting firm demonstrated its product by generating 1174 different proposals at a set site in Malmö. Each proposal showed the output of the sellable area, valid outdoor area, sunlight values, noise level, and the number of corners. The product then highlights the five best proposals based on the chosen governing parameters. It takes the computer less than one minute to filter and generate all of the variants. An example of a site proposal can be seen in Figure 4.4.

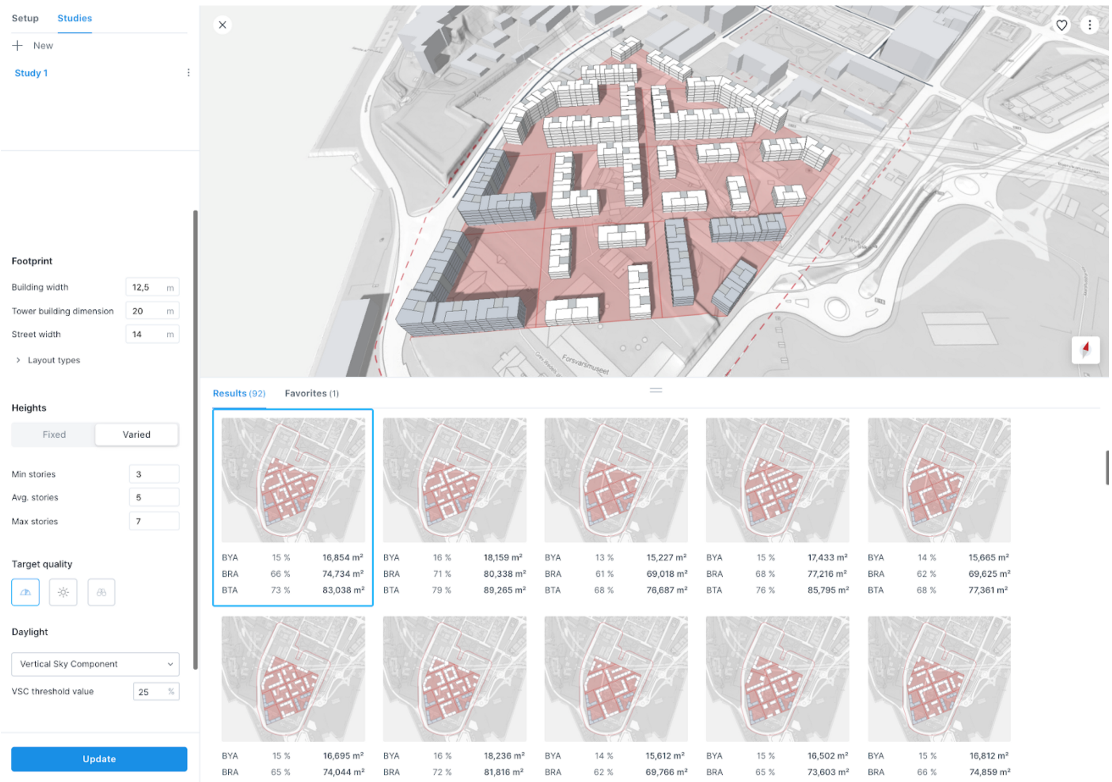

Figure 4.4 *A cloud based generative design tool presenting various site proposals. For each proposal it is possible to choose which parts you are happy with (grey buildings), and which ones you want to continue to explore (white buildings) (Vatn, 2020).*

4.2 Empirical collection

The following chapter gathers participators' reflections on the research objectives, starting with data-driven design methods and architecture. It continues with thoughts on integrating data-driven design methods in the design process and at the architectural firm.

4.2.1 Data-driven design and architecture

Data-driven design methods and their correlation with the architectural profession and knowledge bring spread reflections and attitudes among participants in the empirical findings. The survey shows several positive considerations on the possibilities to improve the design and be more aware of certain design decisions impact on the design.

The continuous feedback enabled through data-driven design methods is compelling for both top management and the employees participating in the survey at the architectural firm. The founding partners emphasize how feedback throughout the design process allows for changes, while specific issues are still open for alterations. The employees repeatedly express how more informed decisions can be made, and better and smarter architecture can be developed.

The lecturer sees great benefits for the designers who can handle the analyzing and simulation tools. She highlights how this can make them deliver more solid design concepts early, resulting in less recast later in the design process. She, as well as the employees, highlights how some analysis today are made by other consultants, often too late in the process, resulting in recast on behalf of design quality. Employees describe how decisions regarding daylight, energy, and other building performance criteria today often are based on rough estimations, if they are even made.

In the survey, employees described how the data-driven methods, especially generative design, open up for other design variations, meaning that it is less possible that one not gets bounded to a specific design idea. The employees participating in the survey express how they often lack time to try and test different design proposals in their design exploration. They see how data-driven design methods could change this situation and create a more iterative design process.

The time-saving benefits are something the consultant sees as an advantage. In his position where he meets many people from different positions in the industry, he finds it very clear that many designers work with slow processes that take time from the "important" work of architecture. The consultant hopes that data-driven design methods will create time for architects to explore and go into depth with their design ideas and create more value with their design. The lecturer has the same thoughts; her hope is that the integration of data-driven tools can contribute to an industry where the early ideas and concepts are more valued than the amount of sellable area or time spent on detailed project planning.

In subsequent discussions of the generative analyzing tool's presentation, many expressed fascinations over the fast generation of concepts and possibilities to get an indication of how to proceed with the design, in the survey where frequent answers related to benefits with generative design application and analysis through simulation that one does not have to work on "wrong" idea over a longer time.

It is also expressed by employees participating in the survey how data-driven design exploration lead to a more collaborative environment since common understanding can be created for the involved individuals in the design team when everyone sees the impacts certain design decisions have. To create a greater understanding of the design through data-driven design methods is expressed as both expected and problematic by participants in the employment survey. In the quote below, one employee describes how the "inner logic" of the project gets lost as data gets too involved in the design process.

> *" When you work in projects, I often think you find an "inner logic" within the project—kind of like finding a solution that was there all the time with respect to its context. When you have found the inner logic, it forces a reformulation".*

The employee continues to describe, how it is challenging to capsize the "inner logic" when the software presents concept since the software does only calculate the variances on the data given to it with no capacity to reformulate the in data.

Several participators stress that the results from data-driven methods should be appropriately examined. They highlight the value of being critical towards the numbers and the importance of creating a realization of the data-driven tools' limitations. One architect in the employment survey express the following thoughts:

> *"A risk of working with simulations is that focus is brought to quantitative data instead of qualitative aspects".*

The employee highlights some examples of the boundaries with simulation and analysis tools:

> *"The flow of people simulations does not consider attraction points, which can be a train station or a nice beach promenade; Investigations of noise do not consider the quality of the sound. People cannot differ between traffic noise and sound from the ocean if they are not aware of the source, but the first feels more negative and the later more positive. People who live in noise-exposed areas near the railways or church bells get used to it and do not hear the noise.*

Employees express how implications arise when it is expected that data-driven design formulates a concept, leading to a blind trust in numbers. In that case, it could harm the architectural design, and knowledge possessed by architects could get lost as a result. It is possible to misinterpret the varying concepts, and one needs to be aware of the boundaries of the data-driven methods. Many highlights how computers only can produce the results within the frames the designer has set. As one of the founding partners express, it is essential to not only choose the data-driven methods but also use more traditional design methods.

> *"The software is no better than the information you provide into it, and how do you verify its validity? By means of data-driven tools should interaction between pen and paper not be laid aside. Sometimes the best propositions arise when you accidentally slip with the pen."*

The anxiety to lose qualitative values and that focus is brought on the numbers exported from the data-driven methods is a concern the employees share while giving their attitudes on integrating data-driven methods in the design process. Some express that there is a risk that the same design proposals will be seen in several designs and that there will mean an environment where everything will look the same. One employee shares his concern in the quote below of an industry where no one has the confidence to make decisions without relying on numbers:

> *"Trends in civil engineering goes undoubtably towards quantitative judgments which also breeds imbecility where no one has the confidence to make their own judgement but must collect words and numbers on every single thing."*

The value of an architect with his/her experience and knowledge and whether the profession's contribution in the built environment will be deprioritized among clients and customers is also highlighted when design development through data-driven design methods becomes so accessible.

The stated anxieties above are something that the interviewed computational designers have understanding for. They express that parameters, algorithms, and design goals will always stand against each other. Through technical development, computers will understand which concepts are valued higher, but only with human supervision. The lecturer highlights that instead of being afraid of these tools, see them as an aid to our design process; we will ultimately create true value. The problem is if we let others who don't have the architectural knowledge control the tool.

To show clients and municipalities different value creation design ideas through numbers and other measurable values are expressed by the top management at several occasions to be something they see as an advantage and need in the digital development of their company. In the Ph.D. student's experience, it is beneficial to show customers measurable values to motivate why one design is better than another. It gives comfort to verify the design while speaking to someone in charge of the money and who might not be as briefed in architectural values as the designers and the design team. Qualitative, soft values are harder to describe in numbers. This creates a need for other tools that can present other descriptions of a design, such as visual descriptions through visualization's or diagrams.

4.2.2 Integration of data-driven tools and methods

The following sections will describe reflections from participants on data-driven design exploration. The structure will follow the one established in Chapter 3.2: First, will the integration of data be discussed, followed by analysis, generative design, simulation, and ultimately iteration.

4.2.2.1 Integration of data

There are today, no clear systems or policies on how data should be used at the investigated company. There are defined standards for how data should be shared and integrated in some projects, but the impression is that these standards are not clearly defined at the beginning of the projects. Data directives are often supplemented as the project proceeds, leading to a lot of manual work in the end.

To collect the data in digital representations of the design, most projects at the company are using BIM softwares. The BIM tools are used during most stages of the design process. Exceptions are the early design exploration projects, smaller projects, and interior projects. The reasons for this are various. According to the ones working in the early stages, there are perceived boundaries in the early design exploration where volume studies, etc. are more comfortable to do in less structured and controlled software. For the other smaller projects and interior projects, there are often architectural designers who are faster and have greater knowledge in other design tools and stay with them.

The BIM models at the company are mainly used for extracting blueprints, coordination, visualizations, and to some extent, quantity calculation of the digital objects. The uncertainty of data directives sometimes leads to an overload of information in the models, where no one really knows what the information is needed for. Several plug-ins are used to handle specific areas in the models, such as detailed information on door specifications, room specifications, etc. The particular software is decided by the clients and also provided by them.

Dependent on the specific project or client, it varies a lot of how information is integrated between the disciplines and at what time in the design process other disciplines are integrated in the design process. In most projects of the firm, the same BIM software is used by the structural engineers. For other disciplines it varies a lot in what type of software is used.

4.2.2.2 Integration of analysis, simulation and generative design methods

The investigated architecture company does not currently, to any greater extent, work with any of the data-driven methods examined in the theoretical framework. There is an expressed interest from the board and several employees to implement data-driven strategies in their current design activities. The survey participants answered whether they wanted to use one generative design or/and analysis and simulation in their design exploration. The distribution of the answers is accordingly with Table 4.4. One also shared an interest in developing specific tools for the company. One person did not answer this question.

Table 4.4: Distribution of the wish to use suggested data driven tools.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Analysis/ Simulation	v		v	v			v	v	v	v	v	v	v	v		v	v		v	v	v	v
Generative Design		v	v	v	v	v		v	v		v			v	v	v			v	v	v	v

The experience with the different methods is limited. Six of the employees have tried analysis through simulation. Two of them have used it at the investigated company. The exploration area has been sun and daylight simulation, structural performance, energy analysis, and people flow simulation. As seen in Table 4.4 do 17 out of 22 want to use analysis and simulation in their current design activities.

While describing the experiences with simulation and analysis as the design-driver in the design process, the Ph.D-student explains how the method often is described to work more smooth and frictionless that what is usually the case. The typical design-analysis integration process starts with a definition of a model and its boundary conditions followed by an execution of the analysis which is followed by the retrieval and interpretation of results. If the results are to be integrated as design drivers, a feedback loop needs to be constructed between model set up and analysis results, typically done with a parametric model. For such a model however the possibilities of variation are set at the inception of the model. However, the initial parametric models may be quite limiting since the design may not have matured enough to incorporate all that you wanted to vary in the end. The parametric approach to design in this case assumes a linear design process logic which is typically possible at the later stages of design refinement, but more difficult in the conceptual stages of design.

According to the researcher, current analysis and simulation tools are better suited while doing a design already made or thought of, where the designer knows what to evaluate against. In the Ph.D.'s professional experience, analysis and simulations were an integrated part of the design process, but it was not always the driving design parameter. He explains the usual usage in the quote below:

> *"In a complex design situation such as most architectural projects the narrative for how a project is communicated varies with the project vision, the client and the task. However, I have experienced tendency in some situation where qualities that are classified as, 'based on subjective judgment' are undervalue, as opposed to what is commonly understood as 'objective values'. Analysis and scientific language can be used as a justifying 'robe' to cove over or motivate decision that were in fact based on experience, and subjective judgement. But the problem is not that there is anything wrong with the analytical approach, rather it is sometimes giving more credit than what it can live up to at the cost of other perspectives."*

The stated complications with analysis and simulations are further mentioned by the employees, as they see a risk and anxiety to implement tools of analysis and simulation. Mainly because they've been on the market for a long time and yet they are not implemented. The tools they are aware of are not developed to work for in a creative design process.

In the Ph.D.-students work as a researcher, new methods are investigated, where one's not bounded to the origin design configuration. Instead, you are able to change the design interactively while simulations are made since the method is developed to handle changes. Such a method could potentially be integrated to improve the early design phases.

The experience with generative tools for the participating employees in the survey was limited. Two of them have some experience. However, are fifteen of them interested in using generative design tools for their design exploration, which can be seen in Table 4.4. They express how they would use the tool for several occasions in the design process, such as volume exploration, site exploration, and generation of floor plans. Common comments with these explorations are that they should be explorative and indicate how a design should proceed. The employees see the tool as a beneficial aid when discussing design with one another and with clients and others connected to the design.

This is also how the invited company that gave a presentation wants their tools to be used. They see their product as a contributing solution to the social, environmental, economic, technological challenges the industry faces. By means of the design process, it is a rule more than an exception that time is critical, and designers cannot iterate and test their propositions, causing room for human errors. The idea with the tool is to create alternative shapes and open up possibilities for analysis quickly. The later can be seen as a communication platform between the disciplines and, last but not least, the client and municipalities.

Since there are several numbers of data-driven tools on the market, the employees express that the most suitable tools for the company should be chosen, covering compatibility and user-friendliness that benefit the creative process. A few survey participants express their feelings of that chosen Building Information software's within the company, and the integration of these are more characterized by compatibility between disciplines over creativity. One employee expresses in the quote below how vital the suitability of the tools is to current design activities.

> *" The interesting in this is probably how the tools fit into the way of working. It's easy to think of an ideal, where it's straightforward to use a parametric design or just simulate/generate the correct design. But the tools are quite old now, 15-20 years old. The ideal is to give a dynamic and optimized product, but the industry may not work with the two in that way."*

To have the generative tool, analysis, and simulation tools integrated into the designing software is something that survey participants highlight and finds advantageous since it is directly integrated into their digital model. At the same time, they found it smooth to use a cloud-based tool like the one presented at the seminar. However, if using that or a similar tool, you might receive a digital model not compatible with the software one is using, and there is a stated risk that there are complications and need of extra work when wanting to reformulate the concept. There are also concerns expressed that if buying external companies' products, it might be hard to integrate soft values.

When the consultant and his team develop methods and programs for their customers, they want to achieve a workable method where their digital tools have a clear role in the design process. While developing analysis and simulation tools, or tools for handling data, they make sure that they are directly connected to the origin design tool.

4.2.2.3 Iterative processes

One of the architectural practice strategies is to have clear trades and reconciliations between the design phases, more or less, as a waterfall method where there are clear breaks in between the phases. They believe this strategy is important for both trustworthiness and learning between the actors of the design. They also strive to achieve architecture that is praised for its creativity and design.

An iterative process that enhances creativity is expressed several times by the employees to be more accessible if data-driven methods and parametric methods were to be implemented at the investigated firm. Today there is a common experience that time is limited for trial and error in the design process. The lecturer highlights how time spent on static modeling in traditional methods could instead be used on creating stronger design processes. Suppose one early on in the design process connects analysis to a parametric model. In that case, it is easier to realize and integrate design solutions that are better designed for sun, lights, wind loads, etc.

The benefits of parametric design highlighted by the survey participant are the effectivization of processes where you easier handle data and minimize the number of repetitive manual tasks. The Computational Designers express how parametric design is the first step you have to control to use generative, analyzing, and simulation tools.

To control and manage created objects without extensive remodelling is a significant advantage with parametric programming tools. Numbers that are important within the project, for example, areas, quantities, and volumes, are automatically generated and easily extracted. This leaves the human factor and its risk of errors with manual handling of data, which, to varying extent, is the way designers at the company work today.

The lecturer emphasizes how the combination of data-driven design methods and parametric modelling is interesting since it enables the ability to develop concepts where both quantitative values, through the analysis, and soft values, through designers' knowledge, can be integrated.

The usage of parametric programming tools is rarely applied to projects at the company. Despite that have 12 out of 22 survey participants some relation to parametric tools. The background of their experiences is given in **Fel! Ogiltig självreferens i bokmärke.**

Table 4.5. Background of the usage of parametric computational design tool for survey participants.

.

	Current Employment	Earlier Employment	During Education
1		v	
2			v
3		v	
4			v
5			v
6			v
7		v	v
8			v
9		v	
10	v	v	
11			v
12		v	v

All twelve who said they have experience in parametric programming tools, and three who have no experience, would like to use it regularly in the design exploration.

Table 4.6 Distribution of the wish to use parametric programming tool.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Parametric programming	v	v	v	v	v		v	v	v		v	v	v			v				v	v	v

As stated in 4.2.2.1 -Integration *of data*, is the BIM software used to a great extent at the company. Since all object in a BIM contains parameters, a parametric programming tool enables an in-depth ability to control the objects and smoothly modify its included information. Building these scripts and helping companies with a structure for parametric programming is something the computational designers devote a large part of their business.

What's regarded as disadvantages from respondents within the company is the difficulty of managing the software and to get the complete overview of the design, causing risks of unforeseen consequences. Parametric design can also be time-consuming, and there are risks that designers work beyond the target scope/constraints and get stuck with modelling with a higher level of detail than the project demands. The tools also give the impression that it is easy to develop something that isn't buildable if you do not lock the properties correctly. There's also a risk that if only a few can manage the software, it ultimately leads to that parts of the project are locked to these designers. However, this is a general risk for all digital tools.

One survey participant describes the "curve of learning" parametric design as non-linear, which can deter many from using the software. The interviewed computational designers mention that some programming tools do not have the required capacity to utilize the programming to the full extent and refers to the case when the software crashes due to a large amount of data. If the simulation causes a crash, the user might need to work around the problem by switching to another software that may not be compatible with the project's BIM-software. If so, you've started a chain of programs required to transfer the model. Which complicates and slows down the effective process.

This chain of transfers between programs and data is, in general, a problem expressed by the Ph.D. student for full integration between competences and techniques. Traditionally, even though you work in a digital platform, there are often many different formats that are needed. While doing an energy analysis, one version of the model is required, a structural analysis needs another one, and for visualization, a third version is required. The purpose of the different formats is to simplify the information used and extracted from the data-driven methods. To create full integration of competences and simulation techniques in the design process, a trend the Ph.D. student sees is the ability to transfer data fast between different programs. Initiatives from various actors, often large and front forwarded offices, are developing systems that can integrate all information and software.

4.2.2.4 Evaluation

The data-driven methods are expressed by the employees to give a greater spectrum for evaluation and the decision-making process. For the computational designer, the perfect design process would be a design team, full of experts, giving their view on the generic models. Then, input from these individuals would guide the further development of the design by analysis and simulation. To have experts from several areas of expertise would make it easier to identify and judge opposing parameters in the concept.

While developing design at the Ph.D. previous employments and there was a need to make conceptual design fast, inhouse experts were invited. Their role were to evaluate and give feedback based on experience and judgment. Since there were clear teams and expertise areas, everyone had significant knowledge within their specific area to base their decisions.

To use analysis and other data-driven tools and employees with particular expertise, the lecturer believes that more solid concepts can be made since intern discussion and requested changes can be made instantly in the model. For companies who do not have the same possibilities to have specific teams to work with innovation and application of innovative methods, the Ph.D. student highlights the importance of relations and openness towards others in the industry. To find collaborators with whom you can have qualitative conversations and a shared understanding for one another is crucial.

The computational designers also share a reflection of how generative software can raise the possibility to involve society in the design process in which citizens could identify values of importance. Another idea is to let them participate by voting on design concepts. They think that generative design can contribute to a more transparent industry, where the development of our built environment is not excluded from society.

4.3 Digital development for architectural organizations

The investigated company's strategic digital goal is to be competent and at the forefront of emerging digital tools. The approach is to follow good and innovative examples in the industry, but not drive and push research forward for new methods. This because of the often-underlying problems with new tools or versions of digital tools. They instead apply methods when significant issues are repaired. One of the founding partners expresses the ambition in the following quote.

> *We perhaps shouldn't be the ones at the furthest top, but absolutely within the top layer. We always want to be associated with competence and not average. If we're average, then we compete only with the prize and is not where we want to end up.*

The survey participants desire in how proactive the company should be in foster digital development can be seen in Figure 4.5 below. The result gives an average of 4.14, where five is the same as to be one of the most innovative and proactive companies regarding digital development.

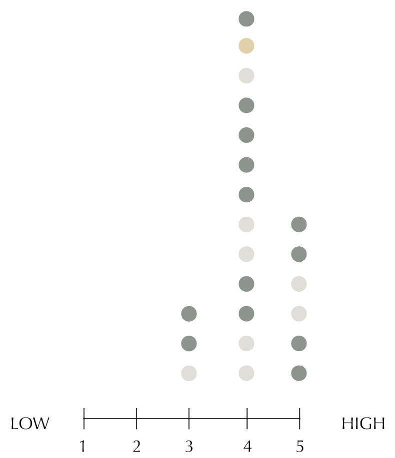

Figure 4.5. Wish of involvement in digital development for the investigated company expressed by participating employees.

The will expressed by the founding partners is to drive the digital progress of the company in collaboration with the client and the specific project so that it contributes to an existing design process. If it is a method that has turned out to be rewarding, then this method should be mass-implement to other projects. The strategy of mass introduction and downscaling the numbers of tools is expressed by both founding partners to be a success factor of the current knowledge in digital tools.

According to the consultant, the strategy to develop together with clients and projects is not enough:

> *"It is not enough to just develop and improve together with the projects and the clients. The projects will always be prioritized, and when you don't know how to proceed, and there is time pressure, you will go back to old habits. "*

The consultant continues to express how this method is both time-consuming and might be twice as expensive. You will manage the task, but you won't improve whatsoever in terms of knowledge. If you have a project, where the economy lets you develop within it, it is a significant risk that the knowledge stays within this project group. It is also clear that if you're not following the technical development, then someone else will get ahead and grab the projects where you would have the change to develop within it. You need to be front forwarded to be able to get the projects where you have the ability to develop.

The lecturer highlight how it requires curiosity and courage to be front forwarded in digital development. To be innovative is most certainly not a smooth path to choose. However, if you are the first architectural company in Sweden, delivering a product developed with methods never used before. Then you are one of the most innovative companies. This will require time and money, but the lecturer believes that there is a need for long-term investments and new approaches to be front forwarded in digital development.

The Ph.D. Student stresses the importance of contracts and the formulation of these to give the right conditions for the execution of innovative methods and processes. His impression is that in the UK, or at least for more prominent international practices, architects have more influence, and if they don't, they make sure they do by contracts. With the contracts and formulations, do the architects have more responsibility for the entire building's entirety and thereby the ability to control the building design process.

To be aware of changing conditions and investigate innovative methods, similar strategies have been applied at the organizations where the Ph.D. student and the computational designers have worked. At these practices, there have been clearly defined specialist teams where people do have specific expertise areas. This approach enables the ability to explore, investigate, and evaluate innovative methods within this specific area. To have specialist teams is ever though questionable regarding the designer's own interest according to the Ph.D. student:

> *"Of course, it is rewarding to have a lot of knowledge in one specific area, but at the same time, the specialization comes with a more specific a narrow scope"*

To have groups with specific areas of knowledge is something the top management at the investigated company has discussed if worth implementing on several occasions. Historically, specific expertise has been laid aside for covering a broad spectrum among co-workers. Working wide is good because you tend to work more flexibly and switch between different types of projects, which they believe is a more exciting work situation for the employees. They also see a risk with specific expertise if you become to characterized by your work and cannot see the full picture.

To have parts of specific expert knowledge from an outsourced company or everything in-house is also questions the top management has discussed. They wish they would've done earlier to gain more competence within the company to have close collaboration with consultants with a lot of knowledge and competence in evolving design tools. Although it's very advantageous of its in-house where you can use the tools during need, there is always a challenge and a risk that you don't keep up with development in the field.

To be aware of changing conditions and innovative methods, the employees in the survey expressed that they would like to see more engagement from the board in observing innovative methods and what is currently going on in the industry. Several employees describe that the company should be more generous with sending more people to participate in lectures, seminars, and webinars. Historically some of the employees have experienced insufficient commitment to network and observe what happens in the industry. It is described that they feel as the attitude has changed recently since new systems regarding digital development have been created. The competence network that is working with knowledge development in digital tools is one of them.

The lecturer and employees express that companies should let people with interest and engagement investigate areas of interest on a deeper level. Time must be set aside for these individuals. The consultant and his colleagues are used to contributing in this phase, working as collaborators or partners while investigating new areas or as support while implementing progressive methods. In the consultant's experience, new methods should be integrated in small steps and not in high-risk projects immediately.

What the consultant seen as another success factor is when the top management is involved and wants to understand the benefits of an improvement. Research of innovative methods should, to some extent, be organized, and there should be some guidelines for the researchers. The company must know what is interesting about a specific area and how they can benefit from it. How it will be presented to the organization and how it is integrated into the projects is also of great importance so that the company knows that they will benefit from it. The lecturer also highlights that the responsible individuals in the design teams need to be curious and have an expressed wish that they want the design to be developed through data-driven methods.

If new methods are to be implemented, the employees express that a clear strategy must be established. It needs to be formulated on how new tools and techniques should enter the design process and how information should be spread in education and courses. It is expressed by some employees how a lot of time has been spent to come up with new methods. But once they have been presented for the company, there is no strategy for implementing the methods in the projects.

The experience stated from the model managers, regarding the implementation of digital methods, is expressed as there are not enough standard work sets and no concise methodology. There is also a lack of clearness for the tasks connected to the different roles, which affect the digital design level. For the model managers, this results in a lot of time spent on other tasks than creating qualitative information-rich models. It is also an expressed frustration by model managers that they have to spend time answering simple questions regarding the BIM tools that could be solved if everyone had some kind of basic competence in the software.

Several participating in the employment survey express that even if they feel like the board supports education and each individual's development, they feel that the time to be educated is not prioritized. With the newly assigned Competence Network, some of the participating employees in the survey believe that the company has realized the importance of investing in digital development. One of the founding partners thinks that integrating data-driven methods is manageable; however there are always issues with time and fitting change into the reality of high workloads and tight project deadlines.

Many point out that the responsibility is not entirely on the management, but also the individual's responsibility; however, many feel as they do not have time to go on education. The problem with time is highlighted by the founding partners who express that even though, or especially when, there is a high workload, education should be prioritized. The employees have also experienced that the way to register to a seminar/coarse has been blurry and energy-consuming, where many people need to be involved before it reaches a decision. Due to this, several expresses that they have not proceeded with education inquires to the board.

5 Analysis and discussion

In the following chapter is the theoretical framework and the empirical findings analyzed and discussed in sorted themes. The investigated company in the empirical results will serve as a case study upon which theories and perspectives will be applied. The chapter is structured so that each section will cover one of the research questions stated in section 1.3.

5.1 Knowledge-intensive design exploration

One of the greatest potentials with data-driven design methods is how it enables designers, design teams, and clients with more information about a design's performance as the design is developed. The following chapter will discuss how data-driven methods could improve the knowledge about the design and ensure a qualitative decision-making process. Ultimately leading to a design reflecting the values established by its creators and thereby answer the first research question:

- *How should data-driven design methods be used in order to add value to a design?*

5.1.1 Knowledge-based design

In architectural design, it is described by Pressman (2012) how several processes are merging at the same time. Internal processes of the designer, such as the creative and cognitive process, are continuing at the same time as external processes such as contextual demands are increased and sometimes changed through the development of a design. Products defined by complexity and tailored towards specifications depend on the knowledge of its creators (Ejler, et al., 2011). The creators of architectural design should, consequently, highly value methods that contribute to extended knowledge.

Data-driven design methods are claimed by Deutsch (2017) to contribute to more knowledge-based design exploration. Information about how well a design performs in contrast to established expectations have historically not been available until a building is produced and used. Resulting in how knowledge about a design is hard to possess as a design is developed. With data integrated into the design exploration, insight in estimated performance is available instantly as changes are made in the design process.

To just be presented with data will, however, not improve one's knowledge. In the knowledge pyramid shown in Figure 3.1, data only becomes information and eventually knowledge when it is sorted, processed, and conferred meaning to (Newell, et al., 2009). The focus and ambition to understand the design through evaluation must be highly prioritized to have a knowledge-intensive design exploration.

There is an expressed concern, both in the theoretical framework, as in the empirical finding, that the integration of more data will mean a blind trust in numbers before human reflection. One employee emphasizes how this bread foulness where no one has the guts to trust their own instinct and judgments. It is described how knowledge will get lost as a result.

Employees, Agi et al. (2020), and Alenius (2016) describe how data don't understand the circumstances of human action or experience. Data-driven methods can't include all variables of human complexity. The moral intuition, described by Friedman and Hendry (2019), has the ability to imagine what impact certain design decisions have on future users, society, and the environment.

As Deutsch (2017) explains, the expression "data-driven design" can be mistaken for acting as the producer of the design. However, it is only given a central role in the exploration, providing the designer with extra information while understanding the building. It is the architect's responsibility to include both qualitative and quantitative values in the design. As Bachman (2019) highlights, architectural design is complicated. It needs concern for scientific and social matters to create a valid response to all the external factors surrounding an architectural design.

To let the designer be in charge of data-driven design exploration is crucial in order to ensure a responsible design-exploration. When designers handle the data-driven methods, the lecturer highlights that true value with a design can be achieved. She explains how designers cannot count on that clients and stakeholders will wait for architects and others in the design team to handle these tools. If others are better at presenting numbers, than it might mean, they will go with their proposals instead. This can result in that qualitative values will be deprioritized.

Architectural design is often described as a decision-making process, where multiple iterations of an intention are processed. Historically, designers have based their decisions on previous experience, facts available at the moment, and imagination and intuition of what the future will bring (Harrison, 2016). The spectrum of decision-making criteria, shown in *Figure 3.11*, describes how decisions can be based on a scale of subjective and objective grounds. Emotions are defined as the most subjective criteria and data as the most objective criteria. In the center of these two is knowledge placed. To search for a knowledge-based design, an intersect between the two extremes should be found.

In Figure 5.1, is the same spectra shown as in *Figure 3.11*, with an extra focus brought on knowledge.

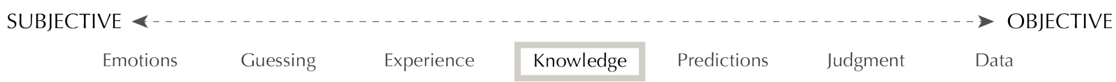

Figure 5.1. *Decision making criteria, focused on the importance of knowledge. Inspired by* Figure 3.11.

To verify the emotions, beliefs, and intuition of why a specific design suggestion is better than the other with data will not only improve the knowledge about the design. It will also strengthen the trustworthiness of the design. The Ph.D. student explains how this is very beneficial, especially when talking to people, not as briefed in architectural values as the designers. Therefore, should data that strengthen the design values be included and shared among participators in the design process.

Architectural design requires the involvement of several individuals. Each design team consists of individuals with different experiences, focus, knowledge, and preferences who have their own opinion of the most appropriate design. Other involved actors in the design process, such as clients and stakeholders, do have their interests, knowledge, agendas, and values upon which they base their decisions. When being presented with data, everyone participating in the decision-making process will confer their meaning to the results with their own specific experience and agenda. Then knowledge will be built by everyone participating in the decision-making process, which will lead to a more knowledge-based decision-making process.

As an architect, it is essential to accept and value the possibilities with data-driven design methods. If data-driven design methods can work in symbiosis with architectural knowledge and methods, and of course, in close collaboration with other areas of expertise, architects and others in the design team can improve their overall knowledge about architectural design and, consequently, create more knowledge-intensive buildings.

5.1.2 Qualitative decision-making

Despite all available information through data-driven design methods, is the architectural decision-making process complicated due to the complexity surrounding the architectural design. Data-driven design methods are often focused on one specific aspect of the building, and the different perspectives are usually in conflict with one another.

Alvesson (2004) claims that complex problems often result in lack of quality when making decisions. The human mind is not wired to include complexity without rationalizing and satisfying the decisions. To ensure qualitative decisions should six elements be included. They are presented by Spetzler et al. (2016) in More than often, an iterative process leads to an outcome, not reflecting what was expected. Through evaluation of the failure, the practitioner gains experience and knowledge. The insight from evaluation helps the practitioner make sense of current challenges and influence decisions for how the process shall proceed .

To make informed decisions in the evaluation, decisions should be based on a combination of critical thinking and the best available evidence described in chapter 0. Critical thinking refers to the process where logic and careful reasoning through reflection, analysis, and evaluation of relevant evidence identify and define problems, connections, and competing arguments. Through the evaluative process, knowledge is extent, and reasoned judgments and conclusions can be made . Critical thinking embrace creativity. When critical thinking is trying to make sense of a problem, creativity is trying to find its solutions .

Unique and complex problems, which are the reality of architecture, often bring difficulties in assessing quality . The human mind is not wired to handle unique and complex problems in an uncertain world without rationalizing and satisfying the decision. To make qualitative decisions, six elements should, according to Spetzler, et al. , be included, shown in **Fel! Ogiltig självreferens i bokmärke.**.

Table 3.6 and will be discussed in the following sections with concern to data-driven design exploration.

5.1.2.1 The appropriate frame

The first element in More than often, an iterative process leads to an outcome, not reflecting what was expected. Through evaluation of the failure, the practitioner gains experience and knowledge. The insight from evaluation helps the practitioner make sense of current challenges and influence decisions for how the process shall proceed .

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Table 3.6, *The appropriate frame,* refers to the ability to specify the problem so that it is clear what is to be decided. Pressman (2012) express how architectural design works in the light of the unknown and arises through iterations, where new information will be brought to the design team continuously. Aksöz (2020) and the Ph.D. student both highlight how it is impossible to know what questions will be answered at the end of a design process. Specifying the design problem is thereby challenging in the reality of architecture.

Evaluating data attached to the circumstances of the design will simplify the process of understanding the governing aspects of the design problem. Instead of answering questions, Spetzler et al. (2016) and Aksöz (2020) emphasize how data-driven design exploration should be used as a guide for framing them. Data-driven design methods can thus help designers creating a conceptual framework for the design.

Creating a concept that can guide the design team in the decision-making process has always been vital in the unknown environment of architecture (Pressman, 2012). In the empirical finding, the lecturer expresses how the integration of data-driven design methods in the early design exploration can contribute to more robust concepts. If there is a strong concept, it is easier for designers and design teams to evaluate the result from data-driven design methods, towards what is desired with the design. A strong concept could, thereby, act as *the appropriate frame* when making decisions in architecture.

To base the concept on just data-driven design results is, however, not an option. The task of architectural design is, as Aksöz (2020) highlights, to find the best solution to multiple objectives. Data-driven tools are often related to building performance and do not include qualitative values, why human reflection is needed. The concept is, as Pressman (2012) express, highly influenced by the architect's vision, where qualitative values can be included. To use feedback provided by the data-driven methods, together with input from people with knowledge from different areas of expertise, knowledge-based concepts will be established.

5.1.2.2 Creative alternatives

The second element of qualitative decision making, highlighted in More than often, an iterative process leads to an outcome, not reflecting what was expected. Through evaluation of the failure, the practitioner gains experience and knowledge. The insight from evaluation helps the practitioner make sense of current challenges and influence decisions for how the process shall proceed .

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Table 3.6, is *creative alternatives*. With data-driven design methods, in particular generative design, it is possible to create multitudes of design suggestions within set up variables.

The employees express how there today is not enough time to explore different alternatives in their design exploration. This is one reason why several consider generative design to be a welcomed feature in their design process. This was particularly obvious when the invited company presented its tool and extracted over 1000 design proposals in just a few seconds.

It is stated anxiety among employees that the use of data-driven design methods will mean that there are just the same variants of design produced over and over again. For a suggestion to be creative, the solution should integrate knowledge and skills with imagination, so that an outcome that is original to what is desired is produced. Nagy (2017) describes how generative design extends the human abilities of design exploration, visualizing aspects which the design team might not have thought of. However, the designers must apply their skills and knowledge to evaluate and elaborate the design suggestions. As the employees' highlight, the generative design can indicate what direction the design process shall proceed.

As one of the founding partners mentioned -making mistakes sometimes leads to the idea from which the best design decisions emerge, why traditional methods should not be laid aside. Through knowledge and experience, the designer can adapt the design exploration and adjust their methods for what is to be explored. Architects are historically used to work with their hands and their brains. This vital knowledge must not be forgotten as the industry more widely adapts data-driven design methods.

Using data-driven design exploration together with the use of more traditional methods, such as physical models, experiments, and drawings, can lead to more explorative design processes and more numbers of creative suggestions than traditionally been possible.

5.1.2.3 Relevant and reliable information

Relevant and reliable information is the third element of qualitative decision making (Spetzler, et al., 2016). As one of the company's founding partners express themselves, "*the data-driven tools are no better than the information you provide into it*".

To critically evaluate the data and make sure it is based on the best available evidence is crucial to ensure that the result of data-driven design methods is valid. Data-driven tools give great possibilities to show measurable values of the design. For the Ph.D. student, it has been beneficial both as a sales pitch as well as a communication tool with clients to explain why one design is better than the other. Just as Deutsch (2015) highlights, if data is used right, it is a great contributor in the decision-making process, where the designer can impact decisions when showing more real facts. Therefore, the data represented in the model must be critically evaluated to contribute to the design process. If data is poorly selected, it can have devastating results, such as false marketing or not contributing to the qualitative values.

Scientific evidence is the first area to consider when collecting information, facts, or data, explained in Table 3.2. Since the evidence and source's credibility and reliability need to be ensured, strategies to obtain these need to be established. With the development in data capacity, more scientific data will be available for designers to take part off. Architectural firms need to invest in these types of data and make sure it is available and used by their employees in the design process.

According to Table 3.2 is the second area to include in evidence-based practices *stakeholder evidence*. To use this type of data, first of all, time to collect information from stakeholders is needed. The result needs to be broken down into variables that can be used in the data-driven design process (Agi, et al., 2020). To break down and integrate opinions, observations, and dialogues is a time-consuming effort. If doing it systematically and with a strategy, it can contribute to more projects than just the current one.

Data such as dialogues and discussion can be hard to break down and integrate into the data-driven methods without risking that important information vanishes. This information should be visually presented in other media, such as diagrams and visual representations, to ensure a valid representation of the collected information.

The third area of evidence to include in qualitative data is *experiential evidence,* explained by Barends, et al. (2014) in Table 3.2 to be information collected in experiments, showing the outcome for specific scenarios. This type of data is often used in building performance analysis and simulations. Agi, et al. (2020) mention that this type of data can be contained from suppliers who have tested their products. To make this type of data available, architects need to be proactive. They need to ask and be determined to collect this type of data. The survey participants describe how it is often unclear what type of data is supposed to be integrated into the models. If architects begin to ask questions about data early on, then a climate where information is more accessible will be the result—both from suppliers and clients.

The fourth evidence is *organizational evidence* (Barends, et al., 2014), which is information collected and kept by organizations such as costs, statistics, customer satisfaction, to name a few. In each project of an architectural firm, there are tons of information available. Having a clear strategy of collecting, sorting, and keeping data within the company and making employees use it is of utmost importance. Wilde (2018) describe the importance of each project to decide and have a clear strategy for what data is needed. Suppose the architectural organizations have a definition of what information and data are meaningful for them. In that case, it will be easier for each project to contribute to a bank of organizational data.

5.1.2.4 Clear values and trade-offs

Just as the appropriate frame do create boundaries for the decision-making process, *clear values and trade-offs* guide the designers in their design exploration. It is the fourth element according to More than often, an iterative process leads to an outcome, not reflecting what was expected. Through evaluation of the failure, the practitioner gains experience and knowledge. The insight from evaluation helps the practitioner make sense of current challenges and influence decisions for how the process shall proceed .

To make informed decisions in the evaluation, decisions should be based on a combination of critical thinking and the best available evidence described in chapter 0. Critical thinking refers to the process where logic and careful reasoning through reflection, analysis, and evaluation of relevant evidence identify and define problems, connections, and competing arguments. Through the evaluative process, knowledge is extent, and reasoned judgments and conclusions can be made . Critical thinking embrace creativity. When critical thinking is trying to make sense of a problem, creativity is trying to find its solutions .

Unique and complex problems, which are the reality of architecture, often bring difficulties in assessing quality . The human mind is not wired to handle unique and complex problems in an uncertain world without rationalizing and satisfying the decision. To make qualitative decisions, six elements should, according to Spetzler, et al. , be included, shown in **Fel! Ogiltig självreferens i bokmärke.**.

Table 3.6 by Spetzler, et al. (2016) to be included when making qualitative decisions and the ambition is to define what is wanted and hoped to be achieved with a design. As already mentioned, is architectural design complex, where several individuals with different agendas and thereby with different values are working closely together. Close collaboration and repeated sessions where values and trade-offs are discussed is extremely important so that certain aspects are not forgotten as the design process proceed.

Each individual or instance of a design team, as well as clients and closely involved stakeholders should be given the opportunity to figure out what their values are, what they want and hope for with a design and what possible trade-offs there are in each situation where decisions are in contradiction to values or wishes. Values of possible stakeholders such as societies, environments and lives affected by the design but not able to be included in these discussion, must also be considered through moral thinking explained by (Friedman & Hendry, 2019).

The computational designer raises the possibility of data to make society more involved in the built environment and the decision process. This is an interesting input, since design decisions involving society are, as already mentioned, based on intuition and moral imagination. A future where society can contribute to further define values of architecture, would most certainly mean that qualitative values are more prioritized since it is harder to ignore the results described with data, than subjective feelings expressed by people involved in the design process.

5.1.2.5 Sound Reasoning

The fifth element of qualitative decisions is *sound reasoning*. The outcome of architectural design is heavily dependent on each design team's capacity and ability to choose between different alternatives, with concern to all included factors of a design problem.

The capacity of data and data-driven methods can collect the included factors and make it manageable to understand a project's circumstances. Reasoning through logical thinking, reflection, analysis, and evaluation of relevant evidence helps the design team realize obstacles, contradictions to value, and the contextual demands. If this part is prioritized in the design process, there are great possibilities that the intended outcome will reach its goals. In Figure 5.2 a visualization of integrated teams and iterative data-driven processes are shown. The purpose of this visualization is to emphasize the importance of a design team with different experience, tacit knowledge, technical expertise, and empathy, which are all part of the evaluation of data driven design results.

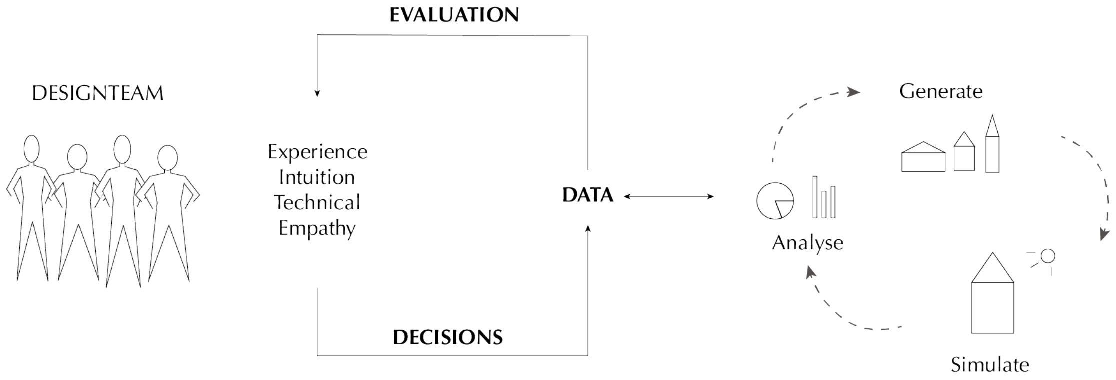

Figure 5.2. Integrated teams and iterative data-driven design processes. (Made by author)

To know how close a design is to reach its goals, Sharp, et al. (2019) highlight that all involved should be allowed to give their critique and feedback in the evaluation of design iterations. The importance of the integration of the entire design-team is key for sound reasoning to reach full potential. Architects should be generous in sharing their results from data-driven results and make sure changes reaches everyone. The client needs to be informed of the importance of systems where data reaches everyone. It should be in their interest to create an environment that can support such processes. By asking questions early on about integrated systems and demonstrating its benefits, doors to a more integrated data management will be opened throughout the industry.

Experience, together with intuition, must continue to be an integrated part of the sound reasoning of a design. To realize the boundaries of data-driven design methods and see their results as estimations, evaluated against experience, is explained by Alenius (2016) to be of great importance.

5.1.2.6 Commitment to action

With data attached to a design, it is possible to prove what knowledge and intuition tell about a design. Suppose emotions and intuition, both strongly connected to the architect's personal attributes and the vision of the architectural design, can be shown and described in complement with data. In that case, it will most certainly be perceived as a more realistic project. To present a design that is realistic, making others convinced that the design would handle complications and needs that are sought to be fulfilled will make everyone more committed and eager to act on the design.

Data-driven design results not only influence clients and other consultants in the design process to stay committed to the design. As employees in the empirical findings hope, they see data as a connector within the architectural design team to reach the same goals and concepts. As Pressman (2012) describes, is the design significantly influenced by the architect's vision. However, there is seldom one designer developing a building. Since a design is developed partly based on personal judgment, and everyone has their preferred design style and design expression, it can be challenging for design teams to agree on design decisions. When it is clear why some decisions need to be made, it will be easier for every designer to engage when they know that it will contribute to a better performing building.

5.2 Integration of data driven design methods in the design process

Data-driven design methods are not new in the architectural market of digital tools. Thus, architectural firms find it hard to adapt them to their current activities. In order for these tools to be implemented so that they create value for the designers working with them, obstacles must be found, and strategies that are simplifying the process of implementing them in the design process must be decided. The following chapters will discuss how the investigated data-driven design methods should be implemented to be used to their full potential, and thereby answer the second research question:

- *How should data-driven design be integrated into the design process to add value for the designers/design team?*

Creative design is not developed in a linear sequence; it is produced through multiple iterations. Iterative processes are described as processes of failure. Carpo (2014) illustrates how the data-driven tools enable designers to *"make and brake"* more design proposals in a few minutes than a traditional craftsman could do in a lifetime. This means that the designers in control of these tools have great possibilities to test and try their design and explore its boundaries. It is described by the employees how there today is not enough time to create iterations of a design, why data-driven design methods are a welcomed feature to their design exploration.

The suggested design process described by (Deutsch, 2017) in Figure 3.5 where constant feedback is provided through an iterative process of analysis, generation, and simulation, enables the designers to control and respond to several of the contextual demands of architecture. However, the process suggested by Deutsch, implies that you are evaluating and integrating data at the beginning of the design process. This is not the reality of architecture; new information is brought to the design team continuously. It is described by both theory and participants in the empirical finding that it is impossible to know what information is needed in the end. Therefore, a suggestion of the iterative design process can be seen in Figure 5.3 where data is an integrated part of the iterative process.

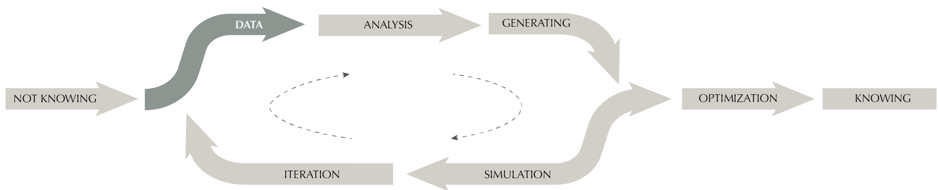

Figure 5.3 *Suggestion of iterative design process, with inspiration from Deutsch (2017) in Figure 3.5. The difference between the two is that data is involved in the iterative process. (Made by Author)*

In the following sections, integration of each of the members in the iterative processes, shown in Figure 5.3, will be discussed and analyzed.

5.2.1 Integration of data

To integrate data in the iterative process, as shown in Figure 5.3, reflects the perspective that no more than the absolute essential information should be incorporated in the digital model (Aksöz, 2020). Moreover, it correlates better with the flexible design process where the level of information increase through the different steps of the agile design process shown in Figure 3.13 by Scheurer & Stehling (2020).

To benefit from data-driven methods, strategies for integrating and sharing data between members of the design process are needed. BIM is the information strategy that has created a paradigm in the industry, simplifying how information is shared between the members of a design process. BIM tools are used by most employees daily at the investigated firm. However, it is mainly used for documentation creation, visualization, and coordination, described by Deutsch (2015), to be some of the most common ways to use BIM tools. To reach the BIM-models potential as a database, where data-driven tools can be integrated, data-strategies needs to be established in each project.

The structure over data is what Wilde (2018) describes as the first step to use data effectively in the design process. The importance of strategies to collect and store reliable and evaluated data is discussed in chapter 5.1.2.3. Having structures for how data should be integrated into the digital representation is as crucial to ensure that data serve the design process. Systems such as LOD (Level of Detail) would simplify the process of creating shared expectations of data. Clear definitions of data and integrated teams is something that Fischer, et al. (2017) value in order to fully exploit the benefits of information-rich design. The company should use systems, such as LOD, to establish a strategy for integrating data into their projects'. A stated strategy would make it easier for the architectural designers to know what data to search for and integrate, as it would simplify how data is communicated within the projects.

To further reach the full potential of BIM will require architectural employees, eager to ask questions about integrated systems of data for all involved consultants in the design project. For the investigated company, it various how involved other consultants are and if there are any standards for how data should be used. The uncertainty for how data should be stored and what amount of data is needed leads to manual reconstruction of the integrated information described by employees to be time-consuming, why such systems should be established as early as possible for the design team.

To handle data more effectively and minimize manual and repetitive work, employees, together with the computational designers, see that parametric programming tools would benefit the workflow at the company. The ability to quickly integrate, change, and extract data from the model is seen as a great advantage with parametric software. This fosters a beneficial environment for data-driven design methods. How parametric programming tools should be used and integrated into the design-model will be described further in *5.2.3- Integration of iterative processes*.

5.2.2 Integration of analysis, generative design and simulation.

Today, analysis and simulations methods are rarely used at the company, and the experience of these tools is limited. There is an expressed interest from several employees and the board to use these methods since they see their value creation in the design exploration and decision-making process. For the firm to integrate these tools, clear strategies and developed workflows are expressed as necessary.

The first step in integrating these systems is to find the tools that suit the current workflows and methods at the company. The employees highlight the importance of compatibility with the current design process and consistent effort in implementing the tools. Data analysis and simulation have been available for decades. Still, it stands clear from both theory and the empirical findings that the tools have not been successfully integrated into the current design processes of architectural design.

The employees describe how they want tools on the market to be evaluated to ensure that they contribute to the creative process. Previous tools are by some perceived as chosen to benefit compatibility with other consultants than promoting creativity. The true value of data can only be achieved while there are integrated teams and systems (Fischer, et al., 2017). Therefore it is essential to find tools that attract both creative processes as integration of data and teams.

Brix Purup and Petersen (2020) highlight eight areas that should be fulfilled while integrating simulation tools. The first one is the tool's ability to be *independent of the design process*. Although analysis and generative design are not the same as simulations, one can assume that the same problematizations follow when integrating them.

The architectural firm has its knowledge spectra in several types of projects, from the early design and site-explorations to construction documents. Data-driven design methods can be present in the entire design process, but they are expressed to contribute most in the early design exploration by both employees and the founding partners. Data-driven design methods have great potential to inform the actors what factors have the most impact on the design performance (Wilde, 2018). In the early decision-making process, where several selections of the design concept are formulated, the information provided from these tools enables an increased possibility to create a concept that is kept intact throughout the design process. To prioritize tools that are suitable and simplify these explorative phases could be a first step in successfully integrating these methods.

As the Ph.D. student illustrates, it is easy to believe that simulation is easy to integrate into the early design process. However, it is described as a complex and often quite challenging process. The simulation process doesn't suit as the design drivers in the data-driven design exploration. A generative design tool works better as the first step in the early design exploration, as shown in Figure 5.3, and the result can later be evaluated and benchmarked with simulations. Before a generative process can be completed, the data must be carefully analyzed to know which design goals the generative tool should optimize the design against.

The data-driven methods do also contribute in the later stages of the design exploration. Designers and design-teams benefit significantly from using them to optimize a design in the later stages, confirming that the design meets set requirements (Wilde, 2018). Therefor is the second criteria: *the tools should be independent of various levels of geometry*, stated by Brix Purup & Petersen (2020), important to take into account when exploring and choosing tools, Even though the tools might first be implemented in the early stages, the tool must be selected so that it can be used in the optimization process of the design development.

The tool's ability to produce both *fast* as *precise* results are also expressed as important features of the tools, stated by Brix Purup and Petersen (2020). This so it can be used for various occasions and detail levels. To use the results of the tools as estimations, where the architectural design team can make changes and fast be aware of its impacts, might be where the tools have the most importance. These results can then be used as discussion material both within the architectural design group and specialists in other areas, who later can confirm and make more precise results in their specific area of knowledge. However, the results must be trustworthy so that design decisions are based on the right grounds. Evaluation of the tool and what kind of data and parameters they use are therefor out of most importance.

Another critical factor is that the tools should have the ability to be used by most employees. People with different levels of knowledge about the tools and also of the specific area of investigation must be able to use the tools. An expressed concern with the integration of new tools is that only a few will have the knowledge to use them, leading to that the potential of the method is not used to full extent. Brix Purup and Petersen (2020) highlight the importance of *differentiated input interfaces* so that non-experts can use simplified interfaces with templates ready to use at the same time as more experienced employees have the possibility to change the parameters so that more precise simulations can be made.

To have tools that are *integrated with the main design tool* is something the consultant, the employees, and Brix Purup and Petersen (2020) see as one of the key factors when implementing the data-driven design exploration tools. The strategic consultant and his company are putting high effort into creating tools compatible with the design process and the main tools they have expert knowledge in. At the same time, it is expressed by Brix Purup, and Petersen that the tools should be *independent of the main tools*, meaning that they should work with some of the most common main design tools. Finding a tool that meets both requirements might be challenging, but still achievable. As seen in the investigated company, are different tools used in various design stages and by different people, and to include all the spectra of projects, it might be impossible just to use just one main tool.

The risk with a tool that applies to several main design tools is that one can't integrate it into the main design tool, which means that one needs to export the model to various formats, resulting in a long chain of exports before changes can be made. This does not benefit the iterative design process, where the impact of changes should be presented immediately as they are made. To have as little variation of main design tools should be sought in order to find data-driven tools that suit the main-tools used at the company. To have a few selected main-design tools is also mentioned by the founding partners as one of the most important strategic decisions to keep a high level of knowledge in these tools.

The generative design tool which was presented for the firm was not integrated into the main tool. It was a cloud-based application, from which you receive a model that more or less needs to be remade in the main design tool. When the next iteration is to be done with analysis, generation, and simulation, you have to re-formulate the ingoing parameters, and you cannot use the existing model which has been developed through the design process. To have a cloud-based tool, as the on presented, is, however, described by some employees to be very smooth since it is accessible and had an intuitive representation of the building exploration. If the tool were developed so that it can be integrated into the main design-tool, it would contribute more to the architectural design process.

The importance of having tools that provide *auto-generation* of the results and *intuitive simulations and visualizations* of the results are the last aspects to consider while choosing a data-driven design tool. The results of data-driven design tools must be easy to extract, and there should be no extra time needed to make them visually understandable. As Agi et al. (2020) express, it is of utmost importance that there are visual representations of the data-driven design results so that an environment is created where clients and the design team can make value-creating decisions.

5.2.3 Integration of iterative processes

For data-driven methods to contribute to the design process, they should provide feedback continuously as changes are made. For designers to be able to answer to the provided feedback, methods, and processes that can handle change are needed. The following sections will analyse the importance of flexible digital models and the importance of processes where results from data-driven methods can be included in the design.

5.2.3.1 Flexible but still reliable digital models

First of all, an iterative process depends on its context (Sharp, et al., 2019). Everything that exists within an iterative process do so because of what boundaries there are. Architectural design is, as already described, dependent on several boundaries. The boundaries of the site, the boundaries of its actor's knowledge, the boundaries of the tools, the boundaries of the materials, to name a few. There are also boundaries such as economic perspectives, desired design expression, concepts, etc. Finally, there are boundaries in economics and timetables.

Keeping track of all the boundaries as a design is developing is more or less impossible with traditional methods. It requires extremely close collaboration between actors in the design process and continuous evaluation of each design change´s impact of all possible aspects that are needed to take into account. Thanks to development in technology and data capacity, several contextual demands can be controlled and kept track of with data-driven design methods, as long as parameters can define the boundary conditions.

The best way to control parameters is by parametric modelling. The integration of parametric modelling as an aid to integrate data is mentioned in *4.2.2.1 Integration of Data* and claimed to be the first step for the architectural practice to have the ability to incorporate data-driven design methods. Parametric programming tools would enable a flexible digital model, where it is possible to change the parameters and data without re-modeling the entire project.

Parametric programming requires a systematic approach in an interface architectural designer are not very familiar with. One employee describes the parametric process as non-linear, and thereby complicated and hard to learn. This might mean that there is some resistance to integrate parametric programming in the design process. Experts, such as the computational designers, who can help define a structure for the scripts, may help some overcome the problems. But as many as possible must have knowledge in the system so that the parametric models are not locked to a few people.

Although parametric programming tools are rarely used at the company today, the survey shows that there are at least twelve people with some knowledge in parametric programming. They are all interested in using it daily. Parametric programming is described by Nagy et al., (2017) as a process where designers can create a more profound understanding of their design. This will gain the evaluative process of data-driven design exploration. Based on the result of the data-driven process, the designer will have more ability to understand what to change in order to further reach the design goal.

An expressed concern with parametric programming is that untold consequences may arise if the model is not properly locked by boundaries. If the models lack information and parametric constraints, inaccuracies may occur, and decisions based on incorrect grounds can be made. When parametric models are built with a high level of systematization, they are very reliable (Scheurer & Stehling, 2020). The systematic approach is ever though questionable in the early design processes. Both theory and empirical findings describe how architects search for as uncontrolled tools as possible when exploring design. Just as for data systematization, the focus should be laid on the right level of systematization of parameters to ensure that the model is flexible enough to handle changes and structured enough to provide reliable results.

5.2.3.2 Flexible processes

The second dependency of iterative processes is the ability for the cyclic processes of intention, process, evaluation, and outcome to flow. The iterative process enables its actors to detect obstacles, contradictions and failures so that creativity will reformulate the design to serve the contextual demands. This process requires time, especially when the contextual demands are complex and often contradict one another. To nurture a process like this, an environment where changes are possible needs to be enabled.

Due to the complexity of the construction industry, the high costs involved, and the complexity of change have resulted in a building design process where there are clear distinctions between phases and changes are handled carefully. In waterfall processes and IPD, it is sought to make decisions as early as possible in the design process. This to avoid late changes and thereby difficulties in managing time and cost schedules. To have clear trades and reconciliation between design phases is also a strategy from the investigated company. This is claimed to be important for trustworthiness and learning. However, these processes do not right correlate with the iterative process, where one needs time to test and correct errors to arrive at the desired result.

Ramsgaard Thomsen et al. (2020) emphasize how current design processes create significant implications for the effective iterative design process. Making decisions early, when most information arises as the process proceeds, can severely damage the result of the design. To foster a design process where changes can be made would most certainly benefit the iterative process and the end product of the design.

As Brix Purup & Petersen (2020) mention, many in the architectural profession propose new workflows and design processes better suited to the iterative and creative design. One must ever consider that changing such established processes as the building design process takes a lot of time.

To find ways to apply data-driven design within the context of building design processes is crucial and explained by one of the employees to be the most exciting part of integrating the tools. This since many of the tools has been on the market for many years but still hasn't been integrated to a general extent. An agile redefinition of the architectural company's stated design process could be made and used as discussion material with clients before a project starts. To just include the information needed does also benefit the agile design process.

To integrate data-driven methods in processes where it is possible will benefit the entity of the project if these are integrated responsible. To focus on integrating data-driven design methods in the early phases, where change does not jeopardize the benefits of IPD processes and waterfall methods, will make huge impacts. The ability to determine most of the contextual demands and establish a strong concept will benefit the optimization phase of the design with less need for significant changes.

5.3 Integrate data-driven design methods in architectural organization's

Data-driven methods have the possibility to severely strengthen the role of architectural companies. To ensure to benefit from the data-driven methods and future innovations that are constantly happening in the industry, architectural companies need to have an environment where change is accepted and adopted. The following chapters will discuss how architectural organizations shall prepare for and integrate change to benefit from the changing conditions and thereby answer the third research question:

- *How shall organizations act to integrate data-driven methods in the design process?*

5.3.1 The impact of the organizational design

To be aware of changing conditions and having the ability to respond to changes, the theory suggests that an organization should be agile. Holbech (2018) describes the agile organization as a living organism, which can self-regulate to changes initiated from external and internal factors. This requires an environment where interactions are continually happening and environments where employees can act based on guidance from simple ruleset and models.

Abilities of interactions are heavily dependent on the organizational structure. The architectural organization structure does not fully follow any of the organizational structures presented in Figure 3.14, but it is clear that it originates from the projectized organization type. The incitement of team and team leaders reminds of a matrix organization. However, the fact that the teams are not separated based on function and expertise, but are somewhat mixed to promote differences in experiences and knowledge means that the organizational structure cannot benefit from the knowledge reversals that take place within matrix organizations.

To integrate clear expertise areas among the employees is something top management has thought of as a strategic initiative. However, a flexible structure where people are able to work with different projects is something that has been prioritized. This since it is easier to place people in various types of projects which are relevant at the moment, and also, they believe this flexibility creates a more exciting work situation for the individual employee. The Ph.D. student also shares the opinion of a more exciting work situation when one is not bounded to a specific task.

Where the Ph.D. student has previously worked, there have been clearly defined teams with specific knowledge, which results in a lot of expertise within that particular area. This system has been very beneficial in projects. Experts from the differentiated groups have been integrated into the same projects, leading to that design decision based on a lot of knowledge. However, it is an expressed concern from one of the founding partners if integrating expertise areas that the individuals might be too focused on their specific area of knowledge, which might lead to the project's entity getting lost.

In Figure 3.13, which compares traditional organizations towards agile ones, it is clear that agile organizations are striving for mixed knowledge in the teams and that organizations should avoid the traditional silo thinking. If the organization strives for an agile organization, they should not invest in separate groups based on their specific skills. Flexibility and multi interaction are two of the key aspects of agile organizations possibility to adapt to changes (Holbeche, 2018).

The organization should be flexible, and the leadership should be spread to more people. Management's role is essential in providing a work environment where innovation is welcome (Aksamija, 2016). The initiative with team-leaders is there for a welcomed feature if the organization wants to go more agile. However, must the team leaders be enabled to act through guidelines and models so that the number of obstacles that slowdowns the process of adapting change is minimized.

For project-based organizations, interaction between the groups is often difficult to enable. With the organizational structure of the company, interactions outside the project groups are created through the team-groups. These groups are today not used for knowledge reversal. They do, however, open up opportunities to more easily connect with others outside the project team. Buy using these groups as a tool to share experiences and knowledge would make the company reach more potential of their organizational structure. Interaction is one of the most important factors when creating shared organizational knowledge and is thereby extremely important in a knowledge-intensive industry such as architecture.

To further share knowledge and standard methods between the projects, an environment needs to be created, where simple guidelines and procedures are shared and used. Settings where people with specific expertise, such as the model managers, are enabled to interact must be created to build common workflows and knowledge. Structures for how information and changes reach all project organization members must also be established so that change is integrated and used by the employees.

The newly assigned *Competence Network* in digital development is an attempt by the company to create an environment where changes can reach everyone. Experienced employees, working with similar roles in history, describe how there has not been enough time to execute the work needed for this type of work. To give the newly assigned network time to create a structure for the detection of changing conditions and methods and platforms for integration of change is central. As PMI (2013) prescribes, shall strategic processes regarding innovation be an iterative and continually evolving process.

5.3.2 Integrate change

The employees highly demand structures and strategies when change is to be implemented at the investigated company. The theoretical framework introduces eight steps of implementing change described by Kotter & Cohen (2012), which will be discussed in the following sections regarding the digital development of architecture.

5.3.2.1 Increase urgency

The first step to creating change is to include a sense of urgency among relevant people. Relevant people are, of course, the board and top management since they are in the position to determine how urgent and compatible the change is with the company's visions. An architectural company is also dependent on the knowledge of its employees. If the employees are not feeling the urgency, they will more likely not act on the change. If people start telling each other that change is needed, it will most certainly mean that more are willing to change. If this wish is expressed to the board and top management by several employees, they will also most certainly be more engaged to enable change.

The urgency of digital development is a constant factor in the existence of architectural practice. The board realizes that efforts in following digital development are essential to be perceived as competent. To be perceived as average is not an option because then would the company only compete on the prize, which doesn't reflect its ambitions. As the strategic consultant highlights, if you are not following digital development, you won't receive the projects you strive for.

To have an engaged top management that understands the benefits of change is one of the success factors the strategic consultant seen at successful companies regarding digital development. Committed leaders that have strategies adapted for change integrated with their operation are, according to Kotter (2012), crucial for both present and future challenges.

Employees participating in the employee survey express that there has not been enough urgency and commitment from the top management regarding digital development. They feel as digital development is a welcomed feature from the board; however, it is expressed that the time and effort needed to be aware of and able to answer to changing conditions is not prioritized. Just as Kotter (2012) and Aksamija (2016) emphasize, are structures and strategies were changing conditions can be discovered needed if the company wants to stay competitive in a continuously faster digital world.

5.3.2.2 Build the guiding team

When a feeling of urgency is created among people in the position to decide if a change is needed at the company, the next phase can be initiated. The following step, described by Kotter and Cohen (2012), is to assemble a team that can make successful changes.

The guiding team could consist of solely employees at the company. With internal teams, the company has a great opportunity to influence the content of what the group is investigating. Kotter and Cohen (2012) describe how people involved in such a group should be selected based on their knowledge and contacts, and the reputation and credibility other employees have for them. The request from employees is that people with experience and interest should be chosen to drive the work in digital development.

Several experienced employees, who also have great credibility at the investigated company, want to contribute to digital development. But they are not interested in being responsible for the work. To find a balance between experienced employees and people who have an expressed interest in managing the work of digital development, but who may not be as experienced could be a strategy for the company to apply to the needs expressed by Kotter and Cohen.

To create a structure where interested employees can explore methods and tools, who are able to involve the experienced employees when their knowledge and opinions are needed is an approach the investigated company could apply. With this strategy, would the company ensure trustworthiness at the same time as people who are interested and have the energy to implement change are responsible for it. To take advantage of the fact that you have interested staff to explore news in the industry is something that the consultant, as well as the lecturer, sees as great importance in the work towards integrating new methods and tools.

The best way to investigate innovations and changes are, according to Aksamija (2016), to integrate research in the organization. Knippers et al. (2020) explain design research, to be the core competence needed for the industry to solve several of the complications that are facing the construction industry. The research groups should consist of people with different knowledge and interests to integrate the entire spectra of architectural design.

The knowledge within the architectural organization is limited. Therefore, strategies to attract more knowledge needs to be established. The top management has, on several occasions, discussed the strategy to integrate more specific expertise into the organization so that more knowledge can be collected inhouse. The reason for not proceeding with this strategy is that they feel as it is hard to verify that you are up to date in the industry. If you collaborate with external actors, it is more likely that they can follow incitements in the industry. However, it is harder to control and affect the results if you use external researchers (Aksamija, 2016). If the founding partners could go back in time, they would have made sure to have close relations with consultants with a lot of competence in specific digital methods and tools.

Aksamija (2016) describes how organizations should evaluate the advantages and disadvantages of having internal people as researchers or implementing external models for research. To have a hybrid approach for research is explained by Aksamija (2016) as a mix between the internal and external research method. Often these hybrid systems consist of a non-profit organization, which is connected to the main organization. This method is something that the lecturer prefers. Research is described to be challenging in the reality of architectural design, such as budget, schedules, etc. With the non-profit organization, it is more likely that the people involved in research will have time to work with development and projects are not exposed to risks.

With this system, you can also choose which part you want in-house and what you want to be outsourced. To reach the full potential of research, collaboration, and the intersection between competences where knowledge and values are directly confronted with one another is, according to Knippers, et al. (2020), required to need full potential of research. The Ph.D. student highlights the importance of choosing collaborators wisely, to ensure that there are shared understandings of each other's values. Integrating knowledge outside of traditional roles in construction industry in the research group, such as social science, is also highlighted as needed to face the complexity of building design.

5.3.2.3 Get the vision right

Aksamija (2016) describes how it is essential to balance an organization's culture, underlying values, and the organizational model when implementing change. Research in organizations can be very costly if there are no relationships between research, design practice, and business performance. For the research team to have boundaries in their research, the organization needs to state its core values and the firm's identity, so that the research team has limitations that they can rely on while investigating new methods and tools.

Based on a firm's values, there are differences in how it operates. Aksamija (2016) describes three primary operations, differentiated based on what they strive to deliver. These are described as *strong delivery, strong service,* and *strong idea* and presented in Figure 3.16.

The investigated company covers a wide range of projects and dependent on cause they are operating in all three of the operation types. It is however expressed on several occasions from the founding partners that their highest priority is to make their clients feel as the provided work is well worth the money. Even if they have a stated design process, there are no clear and stated standards, which is the case for *strong delivery*. And even though they are focused on delivering unique and creative ideas, which is the case for *strong idea* organizations, they realize that not all projects can be unique in every sense. To summarize the company in one operation, the *strong service* is the most appropriate.

The company's ambition is to be top ten regarding digital development. The strategy explained by the founding partners is to develop together with their clients to integrate change as it is needed. Sheil (2020) describes how research incorporated in the project makes it possible for the designer to create greater knowledge since they will have a widespread approach between practice, academy, and industry. To be proactive and suggest innovative design approaches for clients should be a stated ambition among the people responsible for client success at the company.

However, to count on your clients is a risky approach to development. The strategic consultant claims that the project will always what is prioritized, and when there are time pressures, you will solve problems in the ways you are used to, and you won't have the time to explore and improve. Making this strategy more trustworthy, some form of settlement between customer and company should be established, where innovative work is integrated into the task. The role of contracts in such an agreement is highlighted as crucial by the Ph.D. student.

The lecturer expresses how initiatives, where you are brave and dare to take on an innovative role for digital development, can make you perceived as innovative in the future. It will most certainly be a challenging and costly experience, but to dare to take greater responsibility for digital development will create good conditions for the company to be more attractive for clients who want to be part of innovative architecture. Agi et. al (2020) describes how architects should be proactive and be part of the development of data-driven design tools to ensure that the tools are compatible with the design activities of architecture. There is also expressed how knowledge will be increased as the architects explore the boundaries of the tools and methods while creating them.

In the employment survey, did one person express a wish to develop new tools. The approach from the top management is however to follow good and innovative examples in the industry, but not be the ones driving and pushing research forward for new methods. This attitude is partly because of the often-underlying problems with new tools or versions of digital tools. They rather see that they apply methods when significant issues are repaired.

To ensure that they do not lack behind with such a strategy, must the organization make sure they are out exploring innovations in the industry and have continuous communication with companies, such as where the consultant works, so they are following the digital development. To have employees and partners who are attending events, searching for innovative methods, and to participate in different forums where new methods and tools are discussed be prioritized and is highly requested by the employees.

The vision of the company's digital development must also be shared by the employees, or at least understood by them with higher ambitions. From the participating employee's in the survey most expressed a wish that the company should be at the forefront of digital development. One must ever though, take into account that the ones who wanted to participate in the survey do probably, to some extent, have an interest in digital development. This is why the wish of involvement in digital development might be lower than the one expressed in Figure 4.5. For employees who are not interested in digital development, a sense of urgency and interest to change must be established. In this work communication is vital (Kotter & Cohen, 2012).

5.3.2.4 Communicate for buy in

The fourth step of integrating change is to communicate the visions and the strategy of the initiated work. This work is crucial for employees to understand why the change is needed and feel committed to contribute to change. For those who have no interest in change, communication serves as a possibility for them to release their negative energy, so they ultimately can approach the company's visions.

There are different ways to communicate change. According to Kotter & Cohen (2012), the most common way is to provide information about problems, solutions, or progress. This influences how the receiver thinks about a specific situation, and ideas not in line with the presented information will be changed or released. However, this method will not speak to the emotions of the receiver. Attracting someone's emotions is claimed to be the heart of change management. Therefore, the technique to use when communicating change should be the *see – feel -change* method described in Table 3.10.

Just as design suggestions should be easy to understand for clients, shall changes required at the company be easy to understand for employees. Through compelling, eye-catching, and dramatic visualizations, do change-managers help others see the problems, solutions, or progresses through the above-stated method. This will hit the receiver on a deeper level than when information about issues and solutions are provided, without any room for the receiver to understand their own reaction to what is presented.

Architects are, in general, used to communicate their ideas through visualizations to make their ideas stronger. Therefor should the *see-feel-change* methods be easy for the guiding team to apply. It is often discussed how, when visualizing ideas to a client, there always should be room for changes. When the client feels as they can contribute and be part of the change, they are more likely to engage. In the case of architectural companies and change within them, the same strategy can be applied. There should be room for the employees to see the solutions so that their own emotions and feelings for change are awakened.

It is described by Kotter & Cohen (2012) how repetition is key to make everyone eventually feel attached to the initiated change, why there should be several channels where the guiding team can communicate their work and visions.

5.3.2.5 Empower action

To enable people to act, organizations need to empower them to act. The key priority is to remove obstacles in the way for action (Kotter & Cohen, 2012). However, this process cannot be translated directly into handing out more power to a few people. The focus should be laid on creating clear frameworks for which employees can relate their work to. The digital consultant highlights the importance of, to some extent, organized strategies and high confidence from top management should be established for the guiding team so that they have the best possibilities to integrate change.

Management and leadership are expressed as essential to adapt to change. It is described how leadership should be spread on more people and how the number of obstacles that slow down the processes should be minimized. Therefore, the employees who are team leaders and project leaders should have frameworks to go after so that they can quickly provide directions for the employees. As an example, the insight is given in how it is a messy process to access education, where there are many people involved before a decision can be made. Clear training strategies where it is easy for the immediate leader to make decisions is desirable.

For a knowledge-intensive firm, the firm's success relies on the knowledge of its employees (Alvesson, 2004). Therefore the company needs to bread knowledge. As Alvesson explains, a strong knowledge base and collective understanding are essential for such organizations. To create a shared organizational knowledge, focus should be brought on to facilitate that embedded, encoded and encultured knowledge can become shared between the organization's members.

Since embedded knowledge relies on having structures for guidance and procedures, these should be structured and communicated within the company. No architectural project is the same, but several systems and methods can be used in all projects. If standards are communicated to everyone continuously and are easily accessible so that each project easily can integrate them into their respective operation, embedded knowledge of the firm will improve. Encoded knowledge should follow the same principle; information such as manuals, codes of practice, etc. should be easily accessible and continuously communicated to all employees of the project organization.

Integration is essential for all of the knowledge typologies, but perhaps most important for encultured knowledge. The encultured knowledge relies on that the employees of the organization have a common social and cultural understanding. Structures where the company's members can integrate, both within current projects, past projects, and future projects and of course between different projects, is significant. As already mention is the team groups a great incitement for knowledge sharing if used right, other groups where similar competences can meet and discuss should be established. For project organizations, communication must be available so that duplication of work is minimized, and common working methods are made possible.

Lack of knowledge is today contributing to that valuable time is spent on helping people who don't have the necessary knowledge in some of the tools. Wilde (2018) suggests that you start with a workforce's education to minimize current performance gap. For future integration of new tools, education is crucial so that the same problems will not occur again. The employees share that they value encouragement from the board regarding further education. One of the founding partners highlights that they wish that they would put more effort into making sure people are educated. However, a long term of high pressure has made this a low priority. In retrospect, however, they see that priority should be given to this.

What also is emphasized by the employees is a higher involvement in accurate business intelligence through lectures and seminars. The experience from employees is that this kind of involvement has lacked historically.

5.3.2.6 Create short term wins

The consultant highlights the importance of integrating changes in small steps. One of the most common problems claimed by Kotter and Cohen (2012) is that people want to achieve too much at once, leading to that people can't reach the entire goal. To create short term wins, enhance the possibilities that more people accept and contribute to change.

When integrating data-driven tools, it is essential to create goals where new methods have the most opportunity to contribute. The board sees how the data-driven design tools would contribute most in the early design stages, which the employees agree with. Allowing the guiding team to test and integrate the tools, based on real problems, without feeling stress because whether it affects or compromises a projected, is extremely important. However, to find such projects where time is included for experiments and testing are seldom and rare to find. Therefore, the architectural firm must be aware that the first goals may be quite far from the real projects to ensure that there is enough time for testing different tools and methods. However, should the testing reflect how projects and design process naturally develop.

When the time is right for the guiding team to integrate the investigated tools or methods in a real project, there must be thoughtfulness of the most suitable type of project. The smaller projects are not always integrated with BIM, and the more advanced projects might mean that there is too much on stake to incorporate new methods.

This is why the middle-sized projects might be better suited for the first integration of new methods. In these projects, other consultants are often integrated early on, and the clients probably have some data-policies. If they do not, they might be interested in developing a system together. The founding partners have described how they want to integrate new methods in collaboration with their clients. To do so, they need to be aware of the market and guide the clients in a direction towards the vision set up by the guiding team.

When the method has been tried and evaluated, and the result show that it has been a rewarding method or tool, the founding partners express that the strategy is that it should be mass-implemented to other projects. The method of mass introduction and the downscale of numbers of tools and techniques is expressed by both of the founding partners to be a success factor of the current knowledge in digital devices. However, it is described by the employees that a lot of time has been spent on figuring out new systems, and when they are decided to be implemented to a greater extent, there are no clear guidelines. This leads to that methods are not integrated to the full extent. Therefore, the focus to create visions and goals for maintenance and full integration must not be forgotten.

5.3.2.7 Don't let up and make change stick

Maintenance and full integration of new methods require continuous effort from the guiding team to make change stick. The new processes, procedures, or tools will be needed to nature with consistent actions over a sufficient period. To make employees engaged through events that shed light on the possibilities with the change can, according to Kotter and Cohen (2012), make a significant difference. Showing guidance and what the company strives for with new employee orientation and creating roles that show the importance of development will most certainly make people more engaged to take part in the development journey.

If the focus on integration and maintenance of change is not a priority there is a significant risk that the established work will be lost as employees fall back into traditional behaviors. The consultant stresses the importance of enabling time and guidance for the employees to handle the change. When there is time pressure on the employees, and they have already possessed knowledge in how to conquer the obstacles thorough knowledge in less developed tools, they will go back to their traditional workflows, and no one will increase their knowledge. Hence, prioritizing time and strategies for integrating data-driven methods will be crucial to create possibilities for the architectural firm to produce more knowledge-based architecture.

6 CONCLUSION

In order for data-driven design to reach its full potential, this thesis presents methods for how data-driven design methods should be integrated into architectural design to ensure it serves value to the design, the architectural designers as well as the architectural firms.

The thesis presents a literature study that gives a background of the processes surrounding architectural design. It describes an iterative-process of involved components in data-driven design exploration and presents factors needed when integrating data-driven design exploration. The literature study ultimately describes aspects and processes of change within organizations.

The thesis contains an empirical study at an architectural company where observations and semi-structured interviews search for understanding the reality of architectural operation and how it would benefit from data-driven design methods. To further explore data-driven design methods and its integration in architectural design, individuals with experience in the data-driven methods are interviewed. The empirical collection presents how data-driven methods can help designer create more knowledge-intensive design if they are responsible integrated in the design processes. For successful integration must architectural organizations frame processes where tools are holistic implemented. The results from the literature study and the empirical findings are analyzed and discussed regarding the aim of the research.

Below are discoveries from the analysis and discussion concluded. They are presented with respect to the stated research questions.

Architectural design and data-driven design methods

Architectural design is dependent on the knowledge of its creators. Methods and tools that contribute to extended knowledge should consequently be highly valued by creators of architectural design. The data-driven design process has the ability to inform designers what impact their design decisions have on certain investigated aspects and thereby are designers in a position to gain more knowledge about the design. To ensure that knowledge is possessed, designers need to critically evaluate and confer meaning to the provided information. Otherwise, there are significant risks that blind trust in data, and numbers will be established, which can have devastating results on the design outcome.

Architectural design is heavily dependent on its creator's ability to create a valid response to all factors that are surrounding the system, architectural design is complex and requires concern of both scientific and social matters. Complex problems often have difficulties in assessing quality; therefore, strategies that ensure qualitative decision-making are needed. By presenting design solutions with data, it is easier to communicate design proposals, leading to more accessible discussions about values, reasoning, and commitment. Thereby, do data-driven design methods promote the elements needed when striving for assessing quality.

Architectural design-processes and integration of data-driven design methods

When new methods are integrated, their correlation with current design activities must be highly valued. The architectural design consists of several processes, to ensure creative proposals that respond to the established needs of the design, iterative design processes should be strived for. The iterative process lets its actors explore, test, and try their design, ultimately leading to a design suggestion that responds to the external factors. When data-driven methods are integrated into a cyclic process, with reconciliation through evaluation between each iteration, designers are in a position to have control over their design. To ensure the reliability of the design, systems of integrated data, integrated teams, and structured digital representations of the model are crucial.

Integration of data-driven design methods in architectural organizations

Data-driven methods have the possibility to strengthen the role of architectural companies. To ensure that the organization benefits from data-driven methods, they should enable an environment where change can be discovered, integrated, and used. The first step the organization should do is integrate change as a strategic incitement in their operation. The organizations should establish teams responsible for investigating innovative methods and tools to ensure they are aligned with the organization's processes, set values, and goals. The later must be determined by the organization to strengthen the ability to integrate data-driven methods that advantage the organization. Strategies where the changing methods have the time to be integrated, where the guiding team is enabled with high confidence and can develop strategies to promote collective ambitions to integrate the data-driven processes. In addition, the organization must foster an environment in which people within it have the opportunity to integrate and share new knowledge and methods.

Further Research

Two suggestions are proposed for future research concerning data-driven methods ability to improve the construction industry. First, should all disciplines involved in architectural design investigate how their operation, processes, and organizations could integrate more data and integrated data-driven systems to ensure they benefit from such processes. The second suggestion proposes that project management in the construction industry investigates how they can provide environments where data-driven methods can reach the full potential for their design-teams.

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APPENDIX I

1. Historically, what has been the strategy for digital development at the company?
2. What strategic initiative do you think have been most influential in reaching the level of digital knowledge established today?
3. What do you wish you would have done differently to have even higher digital knowledge and skills?
4. What are the benefits of being provided with continuous feedback on your design?
5. When do you think these methods have the most significant impact?
6. What disadvantages do you see?
7. How do you think the possibility is for the methods to be implemented in the design process today?
8. How do you think the organization should work to keep up with future digital developments?
9. What is your goal for the company with regards to digital development?

APPENDIX II

1. What has been your role in digital development at the company?
2. How do you think the work has turned out?
3. How would you like the work in digital development to proceed at the company?
4. How would you like to contribute to in the work ahead regarding digital development?

If actual:

5. What has your work in digital development been like at previous employees?

APPENDIX III

1. What benefits do you see in using direct feedback in the design process?
2. What are the risks?
3. What is required in the design process to create the best conditions for data-driven design methods?
4. What is required of companies to keep up with digital development?
5. What is required of the individual to keep up with digital development?

APPENDIX IV

1. What is your role at the architectural company?
   (architect, engineer, interior designer, other)
2. Do you have experience with parametric programming tools?
   If yes:
   a. What type of parametric programming tool?
   b. When did you use it? (education, previous employee, current employee, other)
3. What are the benefits of using parametric programming tools?
4. Do you see any disadvantages to use parametric programming tools?
5. Do you have an interest in using the tool daily in your work?

6. Do you have experience working with analysis/simulation tools?
   If yes:
   a. What types of analysis tools?
   b. When did you used it? (education, previous employee, current employee, other)
7. What are the advantages of working with analyses/simulations tools?
8. Do you see any disadvantages to use analysis/simulation tools?
9. Do you have an interest in using the tool daily in your work?

10. Do you have experience working with generative design tools?
    a. When did you use it? (education, previous employee, current employee, other)
11. What opportunities do you see with using generative design tools?
12. Do you see any disadvantages to use generative design tools?
13. Do you have an interest in using the tool daily in your work?

14. What would it take for you to start using any of the tools continuously in your design process?

15. Where would you like the company to position himself on digital development?
    - Choose between 1-5 (1= low, 5=high)
16. What is required of the company to reach this level?

17. How do you feel that the company has historically worked with digital development?
18. Have you had the opportunity to develop as you wish?

19. Do you have any other thoughts/comments regarding digital development?