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Development of a standardized design process for utility building elements

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The thesis can be published openly.
The thesis has been conducted according to the TU/e Code of Scientific Integrity

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Preface

This thesis focuses on the standardisation of the design process for utility building elements, which are parametric, modular, and standard designed. The design process enables more standardisation of the utility building industry to enhance productivity, quality, and safety and decrease costs. Therefore, this research is executed in collaboration with Royal BAM Group, BAM Advies & Engineering, and written as the closure of my Master Construction Management and Engineering at the Eindhoven University of Technology.

During my Master, I focused more and more on Technology Entrepreneurship. Consequently, I executed the Certificate of Technology Entrepreneurship and Management, whereby I came in touch with innovation in the construction industry. Furthermore, during my Master, I worked at Royal BAM Group, BAM Bouw en Techniek at Eindhoven, where I focused on the operation and maintenance of larger utility projects. Because I was already involved in the organisation of Royal BAM Group, I already knew that I wanted to graduate with this innovative contractor. Thus, via my colleagues from Eindhoven, I came in touch with Eva Vergauwen, Innovation Manager, working in Bunnik, where the headquarters is of Royal BAM Group.

Together with Jaco Prins, Eva Vergauwen, and Fred de Jonge of Royal BAM Group, I developed this research problem and made a research proposal in collaboration with my supervisors of, the University dr. Q. Han and dr. E. Petrova. They supported me in developing the proposal and the more scientific research approach. During the research, my supervisors at the University were always open to plan a meeting and discussing the progress. The bi-weekly appointments with Q. Han were beneficial.

Furthermore, the weekly meetings with Jaco Prins were open and supported me in the right direction. The monthly meetings with Jaco Prins, Eva Vergauwen and Fred de Jonge assisted more with the more conceptual and practical approaches to the research. Therefore, I want to speak out my acknowledgement for the meaningful meetings with my supervisors of the University and Royal BAM Group. Furthermore, I want to thank the experts I could interview for my research and my friends, family, and girlfriend for their support during my graduation.

This thesis focuses on the standardisation of the utility building industry and therefore enhances the sector to more quality, productivity, sustainability, and safety. This enhancement, i.e., industry innovation, is precisely the direction I want to go in my future career.

Jacco Pereboom

Eindhoven, 28-05-2022

Management Summary (EN)

This study conducted research into the standardisation of the utility building industry. The industry is facing significant challenges to tackle and which the industry should undertake to enable industrialisation. The industry is lagging in industrialisation concerning other construction sectors, such as the residential industry. Industrialisation can enhance the industry's productivity, quality, safety, and financial feasibility. However, with the performance of industrialisation comes standardisation, which implies the standardisation of processes and products, i.e., elements.

Conversely, the current design processes of elements in the utility building industry are not structured sufficient to enable standardisation and industrialisation. The identified causes of this problem are the mindset of the involved stakeholders from the initial moment until the construction and maintenance of utility buildings. Secondly, the organisational challenges behind standardisation concerning the current project approach by contractors.

This research fills a gap in scientific research because this study focuses on the combination of the utility building industry and standardisation, which is a not often researched subject. Furthermore, this study enables an increase in the sector's efficiency and positively impacts socially, economically, and sustainably. Moreover, this study allows BAM Bouw en Techniek to strategize industrialisation according to the primary strategy of the Royal BAM Group.

Therefore, this study developed the following primary research question :

How can the design process of utility building elements be standardised, and how can that process be implemented?

The study defined the next sub questions To answer the primary research question:

1.1. What are the barriers, enablers, advantages, and challenges of standardized design processes?
1.2. How do modularity and parametric design relate to standardisation?
1.3. What are standard design element parameters? Which ones are important for developing utility building elements in a standardized design process?
1.4. What does a standardized design process look like for the utility building industry?
1.5. How should the standardized design process be utilized for the conceptual development of a utility building element?
1.6. How can Royal BAM Group implement a standardized design process to develop utility building elements for industrial construction?

Furthermore, this study applies the design science research cycle of Wieringa (2014) to structure the research. This cycle consists of four steps: 1) the problem investigation, which incorporates the introduction, literature review and interviews; 2) the treatment design, which consists of the development of the standardized design process in a BPMN process map; 3) the treatment validation referring to the conceptualisation of the Hutterelement; 4) the treatment implementation, incorporating the panel discussion and recommendations for BAM Bouw en Techniek.

The literature review focused on the definition of standardisation and indicating the barriers, enablers, and challenges of standardisation. These barriers and challenges focus primarily on the stakeholders' mindset and organisation and specifically on the involved contractors. The contractors have a significant impact on the standardisation and industrialisation performance in the industry. Furthermore, the review describes

the relationship between the design concepts of modular design, parametric design and standardisation. The designer standardises the interfaces between elements and components when applying modular design. With the parametric design, the designer standardises the concerned parameters during the design process.

The research interviewed 13 experts from the industry, from managers and directors to designers of elements. The purpose of these interviews is to understand the current perspectives and practices in the utility building industry concerning standardisation. The experts identify significant challenges to enhance standardisation, including 1) reorganising contractors; 2) the mindset of involved stakeholders; 3) demonstrating these standard solutions.

1. To perform standardisation, contractors need another organisation because the current situation focuses on project-specific developments. In contrast, standardised elements need a concept organisation that develops elements for applying these project transcending. Therefore, using a standardised design process and design conditions.

2. Furthermore, the mindset of stakeholders lags the performance of more extended collaborations and increasing trust between parties. This limited and traditional mindset is present in contractors, advisors, and clients. This mindset involves the sentiment to design and build something specific each time and thereby obstructs standardisation.

3. Additionally, the industry should demonstrate solutions that increase productivity, safety, quality and financial feasibility. By showing standardisation, the contractor can convince other stakeholders. Therefore, this research develops a standardised design process for solutions that meet these requirements. For this reason, the research focuses the most on this challenge.

The research used the literature review and the interviews as input for developing a standardized design process. Furthermore, this process incorporates parametrically and modularly designing. Society requires the industry to increase sustainability, flexibility and productivity, which these two design concepts enable.

The proposed process consists of 12 identified steps to design elements to standard, parametrically and modularly. In these 12 steps, some parts of the element will be designed flexible and other parts standard. By creating an adjustable parameter, the component can meet the context, i.e., dimensions, where the contractor will assemble the element.

This study validated the proposed process by conceptualizing the Hutterelement. This Hutterelement was already designed but helped refer the method according to the practical design of these elements. The Hutterelement is the framework of the fixation of the water reservoir of the toilet, and the toilet itself, in a metal stud wall. This conceptualisation helped make the input of the standardized process practical. The input consists of a workflow for choosing an element to design, standard design conditions, functions, and requirements.

This study conducted a panel discussion to implement this proposed design process for standardizing elements for the utility building industry. This panel discussion helped specify the process and how the contractor should use this proposed approach. Furthermore, this research states recommendations for implementing this proposed process.

According to this research, it is possible to incorporate standardisation with the proposed design process in the industry. However, the contractor faces other significant challenges: the mindset and reorganisation. These two challenges should further research taken into account.

Management Samenvatting (NL)

Deze studie deed onderzoek naar standaardisatie van de utiliteitsbouw. Om standaardisatie en industrialisatie te bevorderen dienen er grote uitdagingen opgelost te worden. Het is belangrijk hiermee aan de gang te gaan, omdat de industrie achterloopt met industrialisatie en standaardisatie in relatie tot andere bouw sectoren zoals de woningbouw. Standaardisatie kan de productiviteit, kwaliteit, veiligheid en het financieel rendement verhogen. Dit onderzoek focust op standaardisatie, dat het gevolg is van het toepassen van industrialisatie, de standaardisatie van processen en elementen in de bouw.

Dit vertaalt zich terug in het feit dat huidige ontwerp processen van elementen voor de utiliteitsbouw niet genoeg gestructureerd zijn om de voordelen van standaardisatie te bevorderen. Een aantal oorzaken zijn vooral de traditionele cultuur en mindset van de betrokken stakeholders van begin tot eind in het hele bouwproces. Een andere oorzaak van dit probleem is dat de organisatie van aannemers niet afdoende is om standaardisatie van elementen te bevorderen.

Dit onderzoek vervult een gat in wetenschappelijk onderzoek dat focust op de relatie tussen standaardisatie en de utiliteitsbouw, dit is een niet vaak onderzocht onderwerp. Bovendien, zorgt dit onderzoek ervoor dat de utiliteitsbouw de productiviteit en efficiëntie kan verhogen met een daarbij positieve impact op sociaal, economisch en duurzaam vlak. Daarnaast kan BAM Bouw en Techniek de strategie in lijn krijgen met de strategie van Royal BAM Group.

Daarvoor hanteert dit onderzoek de volgende hoofdvraag:

Hoe kan het ontwerpproces van utiliteits elementen worden gestandaardiseerd, en hoe kan dat worden geïmplementeerd?

Om de hoofdvraag te beantwoorden worden de volgende sub vragen gehanteerd:

1.1. Wat zijn de barrières, aanjagers, voordelen en uitdagingen van een gestandaardiseerd ontwerpproces?
1.2. Hoe relateren modulair en parametrisch ontwerpen met standaardisatie?
1.3. Wat zijn standaard ontwerp parameters? Welke zijn belangrijk voor de ontwikkeling van standaard elementen volgens een gestandaardiseerd ontwerp proces?
1.4. Hoe ziet een gestandaardiseerd ontwerp proces van utiliteits elementen?
1.5. Hoe kan het gestandaardiseerde ontwerp proces praktisch gemaakt worden?
1.6. Hoe kan Royal BAM Group dit ontwerp proces implementeren voor het ontwikkelen van utiliteits elementen voor industrieel bouwen?

Dit onderzoek past de onderzoekmethode van Wieringa (2014) toe om het onderzoek te structureren. Deze methode bestaat uit vier stappen: 1) probleem onderzoek, dat bestaat uit de introductie, literatuur onderzoek en interviews; 2) probleem ontwerp, dat bestaat uit het ontwikkelen van het standaard ontwerp proces in a BPMN proces map; 3) ontwerp validatie, dat bestaat uit het ontwikkelen van het Hutterelement; 4) ontwerp implementatie, dat bestaat uit een panel discussie en aanbevelingen voor BAM Bouw en Techniek.

Het literatuur onderzoek focust op de definitie van standaardisatie in relatie tot de utiliteitsbouw, identificeert de barrières, voordelen en uitdagingen. De barrières en uitdagingen zijn voornamelijk de mindset van stakeholders en de organisatie van de betrokken aannemers. Deze aannemers hebben een belangrijke bijdrage in het standaardiseren en industrialiseren van de industrie. Daarnaast beschrijft het onderzoek de relatie tussen de ontwerp concepten modulair ontwerpen, parametrisch ontwerpen en standaardisatie. Bij het toepassen van modulair ontwerpen standaardiseert de ontwerper de interfaces tussen de elementen, terwijl bij parametrisch ontwerpen parameters worden gestandaardiseerd.

Tijdens dit onderzoek zijn er 13 experts geïnterviewd van de industrie, van managers tot directeuren en ontwerpers van elementen. Het doel van deze interviews is om de praktijk en perspectieven te leren van de utiliteitsbouw. Volgens de experts zijn er drie uitdagingen voor de industrie om standaardisatie te bevorderen, namelijk het reorganiseren van aannemers naar een concepten organisatie, de cultuur en mindset van betrokken stakeholders veranderen naar een cultuur die hoort bij een concepten organisatie en het aantonen van standaard oplossingen.

Om standaardisatie uit te voeren dienen aannemers te reorganiseren, omdat de huidige situatie binnen aannemers teveel project specifiek is. Terwijl standaardisatie juist verlangt om project overstijgend te organiseren.

Daarnaast werkt de huidige mindset van stakeholders tegen het implementeren van langdurige samenwerkingen en het vertrouwen tussen deze partijen. Deze limiterende en traditionele cultuur is aanwezig bij de diverse betrokken partijen. De mindset betrekt het sentiment om steeds specifiek te ontwerpen en te bouwen.

Bovendien dient de industrie de oplossingen aan te tonen en dat daarbij de productiviteit, veiligheid, kwaliteit en financieel rendement verhoogt. Hiermee kan de aannemer de andere partijen uit de industrie overtuigen. Dit onderzoek focust zich op dit op deze uitdaging met het ontwikkelen van een gestandaardiseerd ontwerp proces.

Dit onderzoek gebruikt het literatuur onderzoek en de resultaten van de interviews als input voor het ontwikkelen van het ontwerp proces. Bovendien worden in dit proces de concepten parametrisch ontwerpen en modulair ontwerpen toegepast. Omdat de maatschappij de bouw vraagt om te verduurzamen en de productiviteit te verhogen, daarom worden deze twee concepten toegepast.

Het voorgestelde ontwerp process bestaat uit 12 geïdentificeerde stappen dat leidt tot elementen die standaard, parametrisch en modulair zijn ontworpen. Dit proces betrekt vier fases van de project life cycle, 1) de initiatief fase; 2) schets ontwerp fase; 3) voorlopig ontwerp fase; 4) definitief ontwerp fase. In deze 12 stappen ligt de nadruk vooral op het moment dat er besloten wordt onderdelen flexibel of standaard te ontwerpen. Met flexibel ontwerpen kan het element worden toegepast in de context dat vraagt om een parameter dat potentieel kan verschillen per bouw.

Dit onderzoek valideerde het ontwerpproces met het conceptualiseren van het Hutterelement. Dit hutterelement was al ontworpen maar hielp bij het praktiseren van het ontwerp proces. Het element is een frame van metal voor het bevestigen van het water reservoir van de toilet, en de toilet zelf aan een metal stud wand. Deze stap hielp in het praktisch uitwerken van de gestandaardiseerde input en output van het ontwerp proces.

Verder is er een panel discussie uitgevoerd om het voorgestelde ontwerpproces te valideren en het praktische bezwaren te weerleggen. Daarnaast hielp de discussie bij het specificeren van het proces en hoe de aannemer dit uiteindelijk zou kunnen gebruiken. Bovendien, definieert dit onderzoek aanbevelingen voor de implementatie van het voorgestelde proces.

Naar aanleiding van dit onderzoek kan geconcludeerd worden dat standaardisatie kan worden toegepast aan de hand van dit voorgestelde ontwerp proces. Desalniettemin dient de aannemer de andere twee uitdagingen serieus te nemen en verder te onderzoeken.

Abstract

A significant challenge for the utility building industry is the industrialisation that it needs to undertake. This industrialisation leads to the standardisation of processes and products, i.e., standard elements. The lack of a standardized design process for components makes it hard to improve productivity, safety, and quality and decrease costs. The current design processes of utility buildings are insufficient for standardising utility building elements.

Therefore, this research discusses the literature on standardisation and how to design with parametric design and modular design. Furthermore, this study executes multiple semi-structured interviews to identify the current practices and perspectives of standardisation. These interviews focused on experts from the industry, from managers to designers. Based on the literature review and interviews, this study developed a standard design process of standard, parametric and modular elements for the utility building industry.

This proposed process consists of twelve primary steps that include modular, parametric design and standardisation. During this process there is a decision included to design element parts flexible, according to the concept of parametric design. Furthermore, the process includes design conditions as input, these focuses on defining dimensions of the element and thereby includes modular designing. As validation of the proposed design process, the study analysed the concerning Hutter element, which fixates the toilet to the wall behind in toilet rooms and includes the fixation of the pipes and other relevant fittings. Furthermore, this study organized a panel discussion to make an extra validation step of this process. The discussion focused on practical implementation and performance.

Therefore, this research developed the first steps to more standardisation of the utility building industry. Contractors can create more elements to standardize projects with this proposed standard design process.

Keywords: [standardisation] – [utility building industry] – [design process] – [industrialisation]

Figure list

Definitions

For this study, it is essential to define the scope of the research area well. Therefore, determining the principal terms used in this study will help restrict the research area. Based on a literature study, this study describes the following terms in consultation with the Royal BAM Group and the Eindhoven University of Technology.

Architecture, Engineering and Construction (AEC) industry is a term that covers that domain where the three aspects of architecture, engineering and construction come together. Furthermore, the definition fits more in Oskam's (2009) review, which elaborates on general, open industry.

The construction industry incorporates the realisation of residential and utility buildings and the GWW industry, which includes ground, water, and infrastructural developments.

The construction industry is the industry that is building the surroundings of society (Snijders, 2016). Defining the construction and utility building industries is vital for developing this study's context. Therefore, this study searched for state-of-the-art literature to determine both industries.

This study elaborates on the construction industry as the industry that incorporates the realisation of residential and utility buildings and the GWW industry, which includes ground, water and infrastructural developments. The building industry contains the completion and maintenance of all types of buildings within the construction industry. According to Snijders (2016), the building industry involves the design, (re-)construction and maintenance of buildings, including all the stakeholders involved in these processes, which implies that the building industry incorporates the residential and utility industry.

Design parameters are the parameters that influence the design of a concerning product. These parameters imply the characteristics that determine the creation of the product. A parameter is any measurable factor defining a system or determining its limits. (Hudson, 2010)

Dynamic construction implies that the designer can standardise some products while other non-standard products should be standardized globally, according to Ballard and Howell (1998).

Element, ''Part of a building or structure considered for standardisation and offsite production, includes foundations, structural frame, envelope, services, internals and modular units'' (Gibb, 2006).

An element contains more specific characteristics; for instance, it will have more building physics characteristics.

Industrialisation elaborated as the movement to the manufacturing industry, the interface between the culture of traditional construction and the culture of the manufacturing industry (Aapaoja & Haapasalo, 2014).

Modular design is ''designing with the focus on prefabricating building components/element/modules and then delivered on-site, based on 3D-dimensional assumptions with innovative design methods.''

Operating company BAM Bouw en Techniek is an operating company of Royal BAM Group that focuses on the development of utility buildings in the Netherlands.

Parametric design is defined as ''the design of a project based on a fixed amount of design parameters, enabling generative computational design based on the input of these parameters and demarcating the design.''

Prefabrication: according to Ballard & Arbulu (2004), prefabrication is making an object in a conditioned environment different from its final position.

Process attributes indicate tasks or influences that the concerned stakeholder performs during the concerned process.

The product can arise at every level of the building deduction. Therefore, it depends on the approach to this term. The product is the physical end-solution sold to the client, the whole building in the construction industry.

Royal BAM Group is the contractor company that is facilitating this study.

A system is the whole building as a system of functions, requirements and modules that meet the clients' demands.

Standardisation is the extensive use of elements, methods, or processes where there is regularity, repetition and successful practice. Simplification of the concerning process or product according to a standard.

A Standard is a rule or norm created by an authority like the European Union to measure quality, weight, quantity, value, or extent.

Unit: a unit encloses usable space and forms the structure of a building. This study interprets a unit as a module, like a room module that does not contain an overall system.

Utility building Industry: the industry that develops utility buildings which are various buildings such as schools, offices or hospitals and therefore differentiates much in shape, appearance and materials.

1. Introduction

The construction industry is facing significant challenges in the coming decades. Currently, the industry is responsible for large amounts of pollution, i.e., CO2 emissions and waste (Heiligenberg, 2020). According to de Bruijn & Maas (2005), the construction industry is one of the main responsible factors for climate change. Another challenge that the industry experiences are significant changes in the working processes and methods (Forcael et al., 2020). With the advancement of new technologies in the industry in the last decades, for instance, Building Information Modelling, the focus shifted towards a new concept: Construction 4.0 [C4.0]. This concept elaborates a new era for the industry, which originates from Industry 4.0[I4.0]. According to Lekan et al. (2021), C4.0 defines the embodiment of industrial development through the technology of I4.0. Within both concepts, state-of-the-art technological methods are the central pillars, including the deployment of digital technology (Lekan et al., 2021). Digital technology and, in general, C4.0 have dramatically influenced the construction industry with Building Information Modelling, new standards, etc., which enable many new opportunities.

As stated, the industry has to change and is currently doing that. Indicators are that more projects aim at innovation, organisations in the industry change their businesses, and the government changes the regulations to acquire a more sustainable built environment. The benefits of Construction 4.0 are embraced more and more and are needed to tackle this transition. Consequently, the industry can develop new business models for enhancing innovation. An already known construction business model is industrial construction. Aapaoja & Haapasalo (2014) define this model in two directions. First is the construction of prefabricated elements in a factory, off-site construction. Second, the construction process is fully standardized and regulated from supplier to construction on-site by the main contractor. This movement toward a manufacturing industry, which is an interface between the culture of traditional construction and manufacturing construction, is understood as industrialisation, according to Aapaoja & Haapasalo (2014). Currently, the industry knows industrial construction as a new business model. However, still relatively new and, therefore, there are still a lot of challenges to overcome.

One of the reasons industrial construction has become more popular in the industry is that many companies struggle to increase productivity and quality and decrease costs (Pasquire & Gibb, 2002). Additionally, according to Ballard & Howell (1998), the industry can learn about complexity, uncertainty, and velocity related to construction conditions of on-site production, unique products, and project forms that are temporary organisations. By focusing on industrial construction (and thus standardisation), the industry can work towards more quality and homogenous construction (Aapaoja & Haapasalo, 2014). Processes from design to construction should be standardized, especially when a company wants to industrialize. Some companies are already standardizing their processes and products to focus on quality, lowering costs, and improving customer requirement interpretation. Standardisation is adopted more and more industry-wide. Therefore, the industry observes a shift in focus toward prefabricating elements. With element prefabrication, the focus shifts towards higher quality, stakeholder management, durability, lead-time, and contract criteria.

Therefore, to embrace the advantages of standardisation, it is necessary to take the following steps. Thus, the construction industry currently performs more and more standardisation, parametric and modular designing. However, some sub-industries are behind in the performance and development of these concepts. The utility building industry lags behind other sub-industries in the construction industry. The utility industry focuses on developing offices, hospitals, schools, and other differentiating buildings. This sub-industry depends so much on the architectural design since these projects differentiate more in shape, materials, and appearance and are hard to standardize (Cadac Group, 2018).

Furthermore, contracts between clients and contractors often do not enable the possibility to perform a form of standardisation. Moreover, Aapaoja & Haapasalo (2014) indicate that the current design processes do not allow a form of standardisation. These factors influence the ability to implement a form of standardisation, while the utility industry considers performing more standardisation, parametric and modular design. Currently, the utility industry tries to standardize some aspects of the processes and products. However, the industry faces challenges in standardisation. These originate in: the mindset and culture of the stakeholders in the whole project life cycle, and the pre conditions of the current design processes of utility buildings are not sufficiently structured to enable standardisation of the construction of utility building elements that are parametric and modular. Furthermore, the industry does not have adequate know-how about implementing these concepts, especially concerning the design process of standardized elements. This study focuses on these insufficiencies and proposes to enhance standardisation in the industry.

Therefore, the objective of this research is to standardize the design process of utility building elements, which ranges from schematic design (SO) to execution design (UO) according to the project life cycle (Moonen, 2018). The proposed design process is based on Business Process Model Notation and represented in a process map, including the organisation of standardized design parameters to design utility building elements. This study proposes a new standardised process based on expert interviews and a literature review. An overview (BPMN map) represents the process's results that involve stakeholders and information exchange. Consequently, the conceptualisation of the process results in the design of an element. Finally, recommendations state how to implement the process and standardisation in the organisation of Royal BAM Group. These recommendations help BAM Bouw en Techniek to strategize industrialisation and innovation processes, according to the primary strategy of Royal BAM Group (2020). Furthermore, this study helps conceptualize theory into practical solutions and focuses on combining standardisation, parametric and modular design in an industry that lags on these aspects.

1.1 Problem definition

Each design of a utility building is unique in shape, materials, and appearance, which makes the design process of these buildings very specific or even one of a kind (Cadac Group, 2018). The lack of a standardized design process makes it hard to improve productivity, safety, and quality and decrease costs (Aapaoja & Haapasalo, 2014; Gibb, 2001). Moreover, practitioners should consider many factors in implementing standardisation successfully (Choi et al., 2020).

The main problem investigated in this study is that current pre conditions for designing and engineering utility buildings are insufficient to enable standardisation of utility building elements. That is parametrically and modularly constructed. As a result, guaranteeing the following aspects is complex, high performance in quality, safety, circularity, productivity, meeting customer requirements, government laws and regulations, and decreasing costs. When applying standard elements and processes, the industry should consider these pre-conditions as design implications.

Furthermore, the contractor can see the advantages of using a standardized design process for utility building elements and how they can use it. However, creating this process in a structured scientific way is currently not in their ability. Therefore, this research will propose and initiate a state-of-the-art standardized design process for utility building elements.

1.2 Research Questions

This study towards standardizing the design process of utility building elements results in the following research questions.

Main Research Question

How can the design process of utility building elements be standardized, and how can that process be implemented?

1.7. What are the barriers, enablers, advantages, and challenges of standardized design processes?

1.8. How do modularity and parametric design relate to standardisation?

1.9. What are standard design element parameters? Which ones are important for developing utility building elements in a standardized design process?

1.10. What does a standardized design process look like for the utility building industry?

1.11. How should the standardized design process be utilized for the conceptual development of a utility building element?

1.12. How can Royal BAM Group implement a standardized design process to develop utility building elements for industrial construction?

1.3 Research Design

Figure 1 states the design science research cycle (Wieringa, 2014) based on which the study bases the overall research structure. The design science research cycle implies the iterative process of problem investigation, treatment design, treatment validation, and treatment implementation.

Literature review: The literature review focuses on the definition of standardisation and how that relates to the construction industry. Then, the study indicates the benefits, barriers, challenges, and advantages of performing standardisation in the construction industry. Subsequently, it reviews the relation of modular and parametric design with standardisation. This section includes the problem investigation phase of the design cycle.

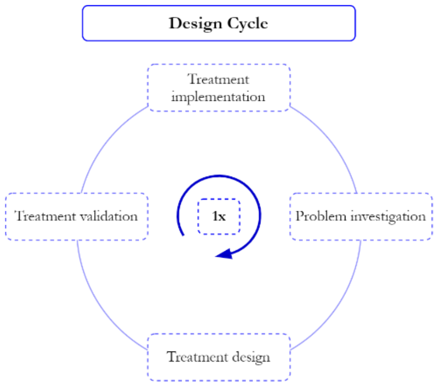

Figure 1 - Design Cycle Process according Wieringa (2014)

Semi-structured interviews: By conducting interviews with experts from the industry, it is possible to research which aspects are essential during the design of a standard element for the utility building industry. The thematic analysis does the analyses of the interviews. The interviews also belong to the phase of problem investigation.

Development of standard design process: the study develops the BPMN process map of the standardized design process of utility building elements. The development of the process belongs to the treatment design phase of the design cycle of Wieringa.

Case Study Conceptualisation: During this phase, developing and designing a utility building element according to the proposed process validates the process map. Therefore, it is the treatment validation phase of the cycle.

Implementation: Afterwards, the gained knowledge and research are implemented and transferred to the Royal BAM Group. This section belongs to the implementation section of the Wieringa cycle.

1.4 Relevance

This study towards standardisation in the utility building industry has relevance from different perspectives. The following points elaborate on these perspectives.

- The benefits of the proposed standardized design process are relevant for society and the industry because it enhances socially, economically, and efficiently.
- There is no research on standardisation specifically focused on the utility building industry in the scientific area. This study fills in that gap.
- Furthermore, this study recommends how to implement and enhance standardisation in the organisation of the Royal BAM Group.
- This study helps BAM Bouw en Techniek strategize industrialisation and innovation processes according to the primary strategy of Royal BAM Group (2020).
- Moreover, this study helps conceptualize theory into practical solutions and focuses on combining standardisation, parametric and modular design in an industry lagging in these aspects.

1.5 Reading guide

This report on the utility building industry standardisation consists of the following chapters.

1. Introduction; this section elaborates on the problem definition, states the research questions, and describes the research design. Furthermore, it discusses the research methods and approaches and displays critical definitions.
2. Literature Review; the review discusses literature concerning standardisation in the construction industry. Moreover, the study examines the current design and engineering process and researches the relationship between standardisation and modular and parametric design. Finally, the study focuses on design parameters and the Information Delivery Manuel according to BuildingSmart.
3. Interviews; this chapter elaborates on the approach of the interviews with the experts. Additionally, it interprets the results and performs a comparison with the literature review.
4. Model - Development of BPMN process map; based on the literature review and the interviews, the standardized design process map for utility building elements is created.
5. Case Study; this chapter discusses how the design process is conceptualized and, thus, performed for designing a standard utility building element.
6. Conclusion; this section answers the research questions based on the conducted research.
7. References and Appendices;

For this research, the framework on page 19, Figure 2. creates an overview of the previous chapters.
Readers with a more technical background who want to know the research structure can read the introduction with the research method and further refer to chapters four and five that develop the process. At the same time, readers who only want to familiarise themselves with this study's main conclusions can read the management summary and the conclusion of this research.

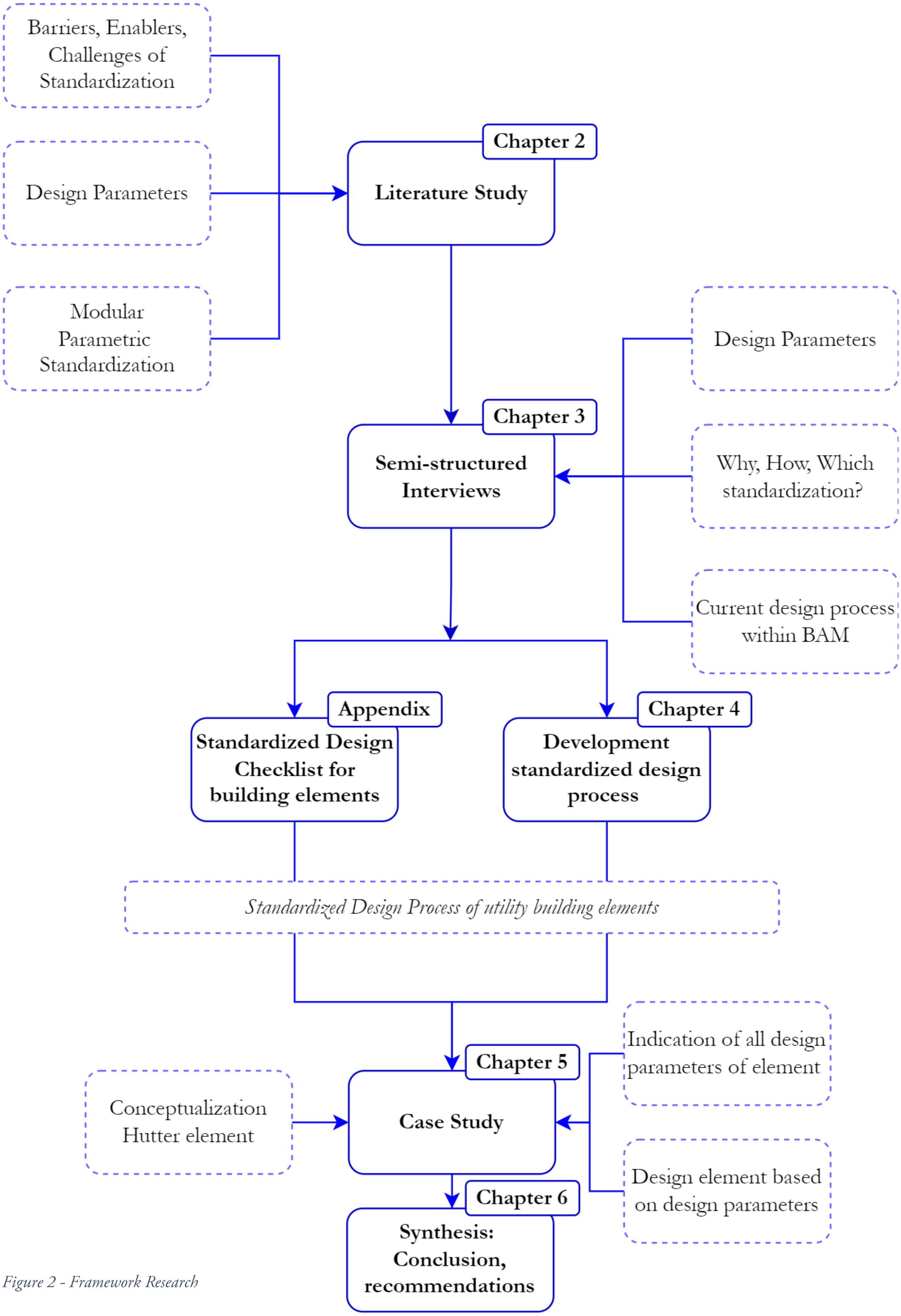

Figure 2 - Framework Research

2. A literature review: standardisation in construction

With the rise of Construction 4.0, the construction industry performs digitalisation and industrialisation increasingly. The performance of these new approaches leads to the standardisation of the construction industry. However, the utility building industry is lagging in the application of standardisation. This literature review studies the application of standardisation in that industry. The concept of standardisation is studied by many, where research (Aapaoja & Haapasalo 2014; Pasquire & Gibb, 2002; Gibb & Isack 2001; CIRIA 1999) states that standardisation can enhance productivity, quality, safety, and decrease costs. With standardisation comes parametric and modular design as two concepts that enable another perspective of utility building elements' design and processes. This review clarifies how that perspective of the design process of elements applies to the performance of the concepts of standardisation, parametric and modular design. This review took a more exploratory approach and therefore concluded that there should be more specific research on this subject in the utility building industry.

Keywords: Standardisation, construction industry, parametric design, modular design, standardised design process

This literature review executes research according to guidelines set by Randolph (2009) to go thoroughly through state-of-the-art research. First, the different aspects of this study will be reviewed and discussed, which are the utility building industry itself and the concept of standardisation. Therefore, standardisation is the main focus of this study. State-of-the-art literature indicates the barriers, enablers, advantages, and challenges. Additionally, the review focuses shortly on parametric and modular designing concepts. It demonstrates how these concepts relate to standardisation.

Purposes for writing this review:

This literature review has the following purposes:

1) Discovering recommendations for the development of the standardised design process;
2) Critical is to identify and discuss essential concepts. There are many concepts related to standardisation. Therefore, identifying the most related concepts is a focus point and thereby debated;
3) After identifying these concepts, the relationships between these concepts should be discovered and analysed.
4) In general, with the literature review, knowledge is gained concerning the context of this study.

The goal of this review towards standardisation is to integrate and critically analyse the gathered literature related to the above-given purposes of this review. With the insights collected in this study, it is possible to develop a standardised design process for utility building elements.

Research Questions Literature Review:

This literature review focuses on Standardisation, modular and parametric design, and how these relate to the utility building industry. The focus is on the following topics:

1. What defines the utility building industry?
2. How are the current design processes of the utility building industry organised?
3. What is standardisation, and what are the enablers, barriers and challenges?
4. How do modularity and parametric design relate to standardisation?
5. Can the most critical design parameters be indicated for utility buildings?
6. What implies a BPMN process map?

Plan for collecting data

The review performs the following method to collect the essential literature. For finding related literature, keyword combinations are made and searched on Google Scholar, Science direct and Researchgate.
Keywords: standardisation AND construction industry
Keywords: standardisation AND parametric design / modular design / barriers / enablers / challenges / advantages
Keywords: utility building design process

Besides the findings from these keywords, four main theses are used as a reference for this literature review and the design research, referring to Heiligenberg (2020), Snijders (2016), Delghandi (2018), and Boterman (2018). Each of these theses has some overlapping aspects with this study towards standardising the utility building industry. Then another relevant article, which is of Gibb (2001), discusses the concept of standardisation in the construction industry and is, therefore, essential for this literature review. It discusses how it impacts the industry and indicates enablers, barriers, advantages, and challenges for the implementation of standardisation.

2.1. Utility Building Industry

The utility building industry incorporates other specifications than the residential industry, which focuses on developing dwellings. The utility building industry is more specifically defined as *the industry that develops utility buildings such as schools, offices or hospitals and therefore differentiates much in shape, appearance and materials* (Vandale, 2021). Thus, the utility building industry is a specification of the building industry. However, in an article in the Cobouw (Oskam, 2009), the definition of utility construction is reviewed, and it questions whether it is still relevant in these new eras of construction.

The article of Cobouw (2009) questions if construction companies should still use the name of utility buildings, seeing that the industry is defined more extendedly. Clients who want to build a new hospital will look to contractors differently than clients who wish to develop new offices because of other construction and design issues. It is now more about a good positioning in the market, according to Oskam (2009), with a modern visual appearance. Furthermore, good communication with the client is more important, which is emphasised by contractors who can dive more into intensive design and construction. While these aspects of Oskam (2009) are relevant, this study uses the general definition stated above because it incorporates essential components.

The scientific literature does not often use the definition of the utility building industry because science focuses more on the construction industry itself. However, a description used more in this field is the Architecture, Engineering and Construction (AEC) industry. This definition gives a broader elaboration than the utility building industry, while it covers the same aspects. AEC is a term that covers that domain where the three disciplines of architecture, engineering and construction come together. Furthermore, the definition fits more in the review of Oskam 2009, which elaborates on a more general, open industry. BAM Bouw & Techniek, which constructs these buildings, does not explicitly define the utility building industry. The organisation does have an integrated approach to determining its market, with the same approach as Cobouw 2009 and therefore fits more the definition of the AEC industry. According to these findings, this study uses the 'AEC industry' to search for relevant literature. This study focuses on the term 'utility building industry' and specifies it as the building industry.

2.2. Design Process Utility Building Industry

This section of the literature study elaborates on the entire design process of a construction project. This design and construction process is needed to indicate the current situation in the utility building industry. Therefore, this section discusses the main aspects of this process that involve the following aspects. First is the involvement of stakeholders, and secondly, the applied contracts. And third, how the entire process is structured. The process focuses on the current general project life cycle, and its application is to the utility building industry.

Figure 2 introduces the overall design process and the project life cycle. This figure indicates the different phases a current construction development process is facing. The project life cycle is based on Dutch definitions by DNR-STB (2014), focusing on the Dutch construction industry. This process influences standardising the design process of utility building elements. Therefore, this elaborates on the project life cycle. This life cycle consists of two processes that overlap: the design and engineering processes. When there are many design iterations during the design process, the stakeholders can influence the design (Delgandhi, 2018). After creating the design, first, the engineering of the plan takes place, whereafter the execution phase will start.

Standardizing the design process is essential in creating common thinking and approaches because the industry has to deal with many stakeholders. Furthermore, by discussing the project life cycle, the basis of standardisation in the industry is elaborated and can be a starting point for developing the standard design process.

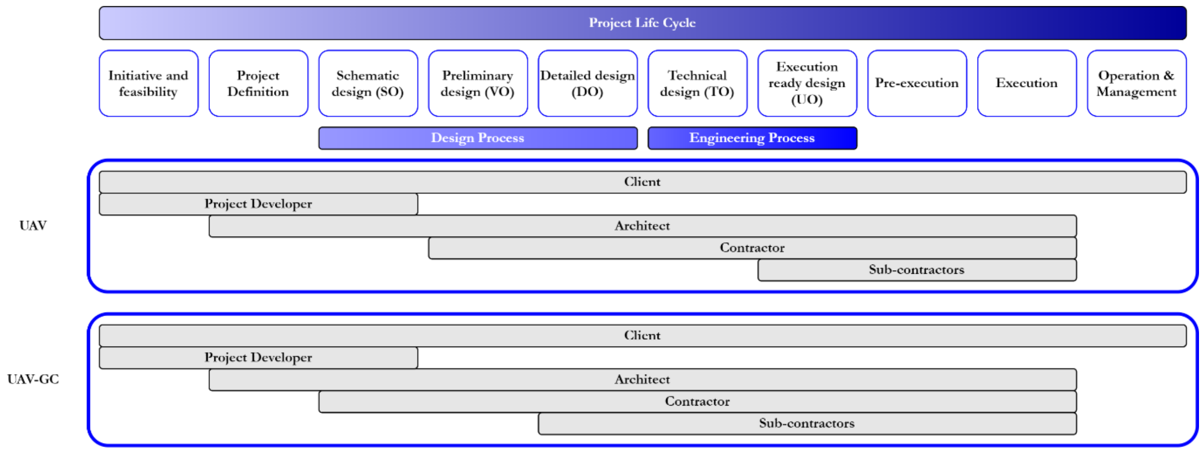

Figure 1 - Overview project life cycle with contract models

According to Reed & Gordon (2000), Song et al. (2009), and Knotten, Laedre & Hansen (2017), there is agreement that total integration of design and engineering in an early design phase gives the best results for successful construction. That will result in lower costs and more integration of design, construction, environment and other economic systems. With early integration, standardised building elements are easier to implement in the design, so this phase is crucial to creating a successful project (Knotten, Laedre & Hansen, 2017).

Combining design and engineering makes standardisation easier to implement, and a project will cost less. Figure 4 below, the MacLeamy Curve, implies that earlier engineering involvement with design increases efficiency and decreases miscommunication of requirement verification. Some challenges arise during these design and engineering processes, and the following sections discuss the challenges that influence standardisation.

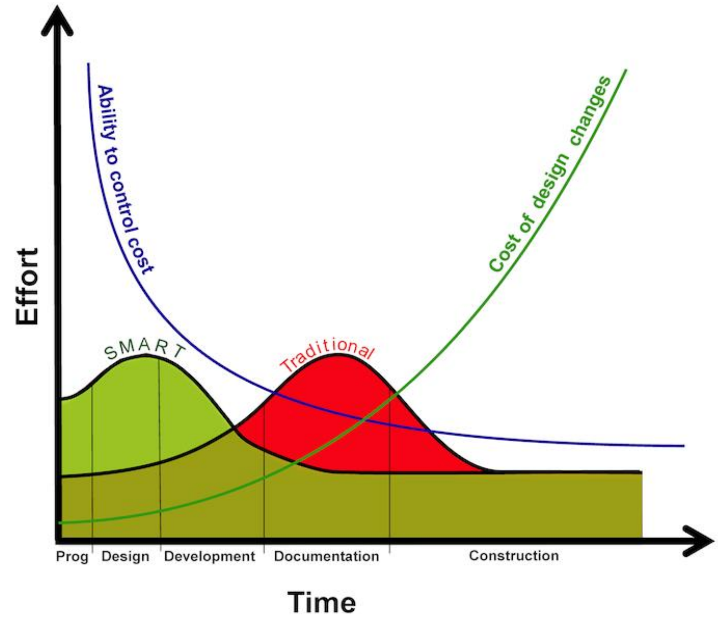

Figure 4 - MacLeamy Curve - source: MacLeamy IDEAbuilder. (2012).

2.2.1. Challenge 1 Contracts

The currently used contracts in the industry impact how contractors can apply standardisation in a project. In the industry, it is common to distinguish different contract forms that mainly differ in liability and how the client has influence, according to Chao-Duivis et al. (2018). The utility building industry applies two different contracts: the UAC 2012 and the UAC-IC 2005. These two contracts have many influences on the project life cycle processes, which Figure 3 shows, and on the responsibilities of stakeholders. Furthermore, with the development of a standardised design process for utility building elements in this research, the contract type used per project influences how to structure the proposed approach.

The building contract – UAC 2012
The traditional model states that the contractor, contacted by the client, should execute the design that the client delivers (Chao-Duivis et al., 2018). In this model, a consultant creates a design for the client that a contractor should execute. Therefore, the leading industry perspectives indicate this is a traditional model. With this contract model, it is hard to have any form of influence on the design. In the context of this research on the performance of standardised elements, this contract model has its limits and needs to be studied thoroughly.

Integrated contracts – UAC-IC 2005
This contract form is a more open model where one organisation is reliable for the design and execution of the project (Chao-Duivis et al., 2018), which means that the contractor of the project is already involved in some cases during the design of the building. Furthermore, contractors could add multi-year maintenance to the contract (Crow, 2005). In this model, the contractor has more influence on the design, and therefore it is less complicated to implement standardised building elements in the project.

The contract models used in the utility building industry differ in some aspects. The central aspect of this study is the difference between the influence on the design of a project. The more influence on the design, the more standardisation can be performed. Thus, a UAC-IC contract can enhance standardisation more than a UAC contract. This study did not yet identify the specific challenges of the UAC contract model. The interviews with experts will give insights into how it influences the design and if the use of standardised elements is even possible when a contractor applies a UAC 2012 contract model. In conclusion, implementing a UAC-IC contract makes applying standardised components based on a standardised design process possible to implement.

2.2.2. Challenge 2 Design Management

The AEC industry is facing an issue that current projects are not yet managed very well during design (Knotten et al., 2015). That leads to document deficiency and more rework. Furthermore, the quality of the design and project will be lower. According to Knotten et al. (2015), this results in the fact that managing the design process is one of the most complex tasks because there are many flows of information. This challenge arises around design management because this concept interrelates with the focus on standardisation. The following section discusses the concept.

This design management is essential for controlling the flow of information and stakeholders in this process. Therefore, all stakeholders must know their position in the process and how and when to take action. Thus, process models are essential (Emmitt & Ruikar, 2013). Consequently, according to (Knotten, Laedre & Hansen, 2017), productivity and quality are related to efficient building design management.

This design management implies the management of output, i.e. drawings, and the creative mindset to design the project. In other words, it is the management of the stakeholders and the design itself. Knotten et al. (2015) indicate four aspects of how information flows while conducting a task. Figure 5 shows these differences between the four types of processes.

It is vital to recognise what type of process is applied to manage these. Therefore, these four processes are indicated and can be involved in the proposed design process of utility building elements.

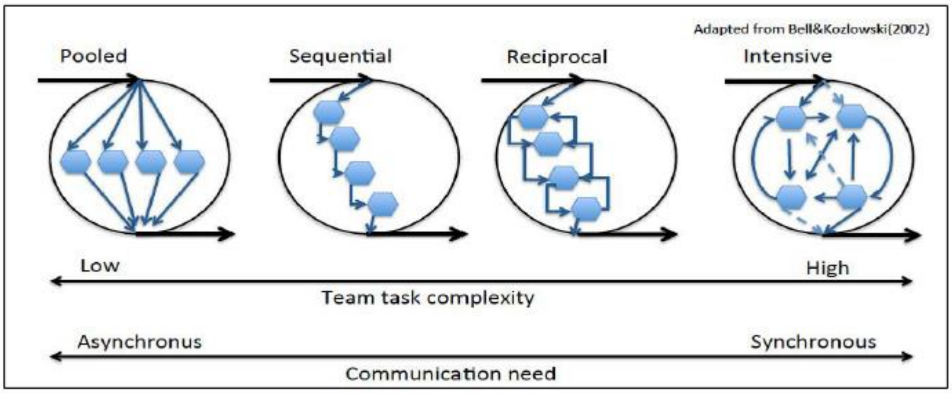

Figure 5 - Type of processes of a task - source: Knotten et al. (2015)

2.2.3. Challenge 3 Information exchange during the design process

Much information is exchanged during this design and engineering process in the construction industry, as concluded from the MacLeamy curve and the relation with the concept design management. Nowadays, it is one of the biggest challenges in decreasing costs. Too many errors are still not eliminated in all these communication processes. One of the essential flows is between design requirement and design solution. Therefore, verification is needed to coordinate this information flow. BAMinfra (2008) indicated how this flow is organised in the design process, shown in Figure 6.

By using standardisation in the design and engineering process of utility building elements, the verification phase will be shorter and more fixed, resulting in fewer mistakes during this engineering phase for the elements. The use of standardisation makes it better to make reasonable interpretations when a consultant comes up with a design solution to answer a requirement. Therefore, the solution can meet the customer requirements better.

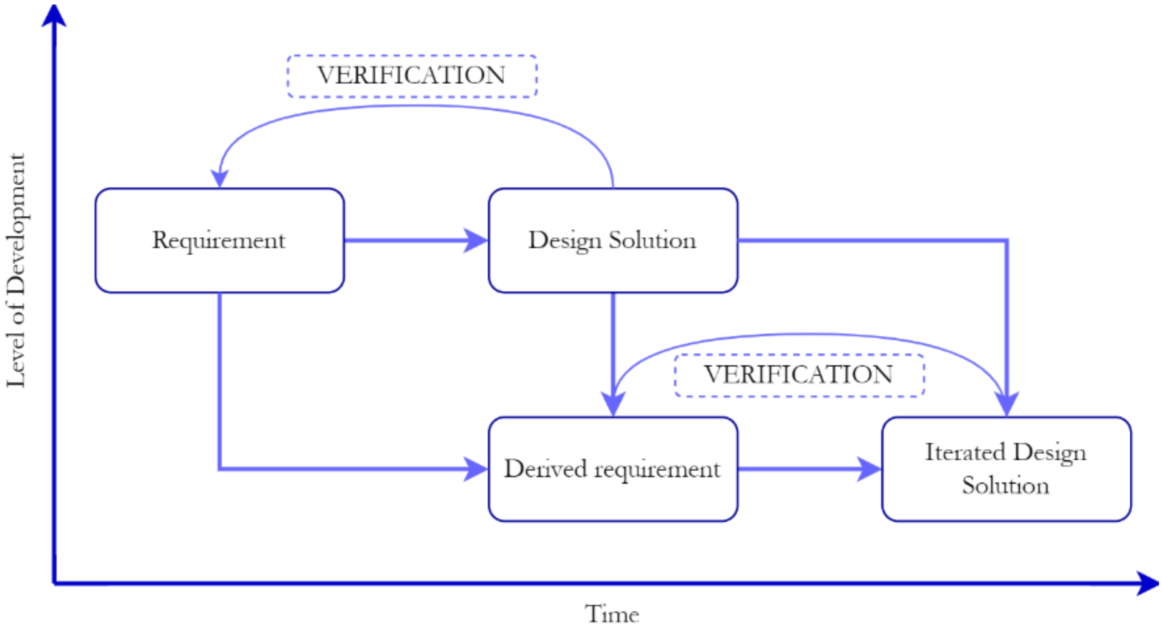

Figure 6 - Requirement Interaction - source: BAMinfra (2008)

2.2.4. Conclusion design process

The design and engineering process of the utility building industry is relatively traditional, impacting how to implement the new developed standardised design process. Furthermore, different contract models make it hard to conclude how a standardised design process can fit in. With a UAC 2012 contract, the contractor should precisely execute the design, making it hard to implement a form of standardisation. While with a UAC-IC 2005 contract, one organisation does the design and construction of the project, enabling more standardisation. According to this review of the design process and management, the study concludes that standardisation can enhance these design challenges. By standardisation, the contractor can optimise the design management and tackle the design and engineering process challenges. Furthermore, information exchange and requirement verification can be more structured when a standardised design process of utility building elements. Moreover, early involvement of the contractor during the design process is maybe the most important conclusion to enable process and product standardisation.

2.3. Standardisation in the construction industry

This second part of the literature study elaborates on the concept of standardisation. The focus is on defining the concept and indicating the barriers, enablers, challenges and advantages of standardising in the construction industry. By focusing on these central aspects of standardisation, it will be clear how to apply standardisation in the construction industry.

2.3.1. Review standardisation

Standardisation is a concept that is already a widely discussed subject in the construction industry. However not yet sufficient in the utility building industry. The idea can enhance different aspects of the industry. For instance, it can decrease the costs of projects. Furthermore, it will help get all the persons involved in the process to go in the same direction because standardisation influences the development of a product. Seeing that the utility building industry is performing less standardisation as a concept in processes and products, it can be a positive influence and could enhance the industry. This section focuses on state-of-the-art literature that elaborates the definition of standardisation based on six aspects that embody standardisation. The following six aspects are indicators of the meaning of Standardisation: 1) rule, norm; 2) repetition, regularity; 3) systematic approach; 4) process, product; 5) successful history; 6) shared structure. The literature discusses and reviews the concerning standardisation that identifies these indicators.

Many studies performed research on standardisation in the construction industry. Some studies focused on the general concept of standardisation in the construction industry and elaborated on the challenges and barriers (Aapaoja & Haapasalo 2014; Pasquire & Gibb, 2002; Gibb & Isack 2001; CIRIA 1999). Other studies focused on a specific concept application (Boterman, 2018; Poljanšek, 2017; Choi et al., 2020). The focus was on how standardisation could improve the construction industry.

1. Rule, norm: This indicator focuses on the same concept or idea, the designer following that design rule. The report of Poljanšek (2017) focuses on BIM standardisation and defines that concept differently from the other literature. According to Poljanšek (2017), standardisation is the development of society close to a norm, thereby performing the norm.

2. Repetition: The study of Gibb & Pendlebury (2006) includes repetition in words "*in which there is regularity, repetition*" in their definition of standardisation. That implies that there should be a repetition of the activity or product that the contractor should standardise. Other studies like Pasquire & Gibb (2002) and Gibb (2001) elaborate on the same over repetition as Gibb & Pendlebury (2006).

3. Systematic approach: The research of Perumal & Bakar (2014) describes this approach in the application of process document standardisation. That differs from the definition of Standardisation by Gibb & Pendlebury (2006). They discuss that a form of coherence is created with standardisation to enhance procedures and reduce clashes between employees. That leads to increased efficiency and better communication between employees.

4. Construct: The study by Münsterman & Weitzel (2008) focuses on business process standards and concludes that standardisation can be defined based on four main aspects, according to de Vries (1999), which are: 1) entities; 2) the industry where it is applied; 3) the goals of standardisation; 4) the method organisations are performing standardisation. The construct, in this case, what this study standardises, is defined as an entity to standardise. Gibb & Pendlebury (2006) elaborate on the construct: "*This may include standard building products, standard forms of contract, standard details, design or specifications, and processes, procedures or techniques.*"

5. Successful history: With this indicator, previous learnings and successes that enable standardisation are essential and thereby added to the definition of standardisation. Gibb & Pendlebury (2006) state that the standardisation bases the purpose on achievements and learnings.

6. Shared structure: The study of Poljanšek (2017) elaborates that standards enable a collective mindset for performing processes and adequately interpreting the aspects, which indicates the shared structure. The shared system is the same strategy and philosophy between individuals and organisations to enable and perform standardisation.

This study made a synthesis matrix, as shown in Table 1. State-of-the-art articles are reviewed on the definition of standardisation. Two studies (Munsterman & Weitzel (2008) and Poljanšek (2017)) were not construction-related. They had, therefore, other insights, while the most general studies did a literature review on the concept of standardisation in the context of the construction industry. Based on six main aspects of standardisation, this study reviewed state-of-the-art literature.

Publications	**Aspects**					
	Rule - Norm	Repetition – regularity	Systematic Approach	Process/product	Successful history	Shared structure
Aapaoja, Haapasalo (2014)	X					
Choi et al., (2020)			X	X		X
Poljanšek (2017)	X		X	X		X
Gibb (2001)		X		X	X	
Gibb & Pendlebury (2006)	X	X	X	X	X	
Gibb, Isack (2001)		X		X	X	
Munsterman, Weitzel (2008)	X			X		X
Pasquire, Gibb (2002)		X		X	X	
Perumal, Bakar (2014)	X		X	X		X

Table 1 - Synthesis matrix review standardisation

The term standardisation can be very broad elaborated, concluded from the definitions given above. There is no specific definition used industry-wide that more researchers study. The primary description used in the industry is currently from Gibb (2001). Gibb (2001) elaborates on this concept very broadly and could therefore define standardisation in a comprehensive method. However, there are still some differences within the concept of standardisation. These differences focus more on the application of the concept.

Literature applies standardisation in two ways, and this application determines in some way also the definition of the concept. First, products can be standardised, implying using many products based on the same assumptions. However, a contractor should standardise the design and engineering processes with standardised products. Thought when the contractor standardises the process, the products can be standardised afterwards, according to Aapaoja & Haapasalo (2014). Thus, a standardised process does not directly imply standardised products. However, the contractor should also standardise to effectively use standardised procedures (Aapaoja & Haapasalo, 2014).

On another note, it is crucial to apply standardisation with the correct method. According to Poljanšek (2017), it is essential to elaborate on which sector uses standardisation because the application and definition differ per sector. Besides the difference per sector, there could also be a difference per organisation, where the concept is more strategically applied.

According to the reviewed literature, this study chooses the following definition for the research towards standardisation in the utility building industry.

Standardisation is the performance of implementing a standard/rule of a construct with repetition based upon previous learnings. Organisations/stakeholders propagate standards/rules and enforce them according to a systematic approach.

The definition of process standardisation is still comprehensive and hard to define more specifically. Therefore, the following description is specific to the utility building industry, with the assumptions: 1) the standardised design process; 2) the design process of standardised utility building elements. Then, based on this context, the definition is:

Standardisation in the context of this study towards the utility building industry is the performance of implementing a ***restructured*** *design process of utility building elements that do not restrict* ***design choices****. Based on a design of elements that is standardised, modular and parametric according to previous learnings focused on standardisation. Furthermore, the contractor implements it by a systematic approach, which implies a collaborative mindset between different stakeholders and partners.*

The design choices indicate that the design of an element contains more standard decisions and is, therefore, less flexible in the design, which implies the design freedom refocuses.

In conclusion, this standardisation review is based on state-of-the-art literature and summarised in a systematic matrix. Based on six standardisation aspects, it indicates how different literature defines standardisation. The study shows that a construct, the standardised process or product, is the central described aspect in the literature. Furthermore, the rule or norm is an aspect that is important for the definition of standardisation. That implies the standard that the concerning construct should follow. Otherwise, there is no form of a standard.

Then, the review elaborates on the definition of standardisation. Thus, it describes the identified barriers, challenges, benefits and advantages. The obstacles indicate the aspects that do not enable a form of standardisation in the construction industry, while the benefits are the aspects that allow standardisation. Then, the challenges indicate the factors and tasks to overcome to promote standardisation.

2.3.2. Barriers

According to the first part of this literature study on standardisation in the utility building design processes, there are still some barriers to implementing standardisation. A literature study executes the review to get thorough insights into these barriers, which can help the performance and execution of standardisation. Therefore, Figure 7 creates an overview of the main obstacles. These barriers indicate insights into how these barriers block the implementation of standardisation.

Four general studies did studies towards standardisation and especially also on barriers, which are Aapaoja & Haapasalo (2014), Pasquire & Gibb (2002), Gibb & Isack (2001) and CIRIA (1999). Therefore, the review focuses on these four studies. Based on these reviews, the study created the following Table 2. That matrix indicates which study discusses which barriers.

Barriers	Publications			
	Aapaoja, Haapasalo (2014)	Pasquire, Gibb (2002)	Gibb, Isack (2001)	CIRIA (1999)
Failure to consider all relevant costs		X	X	X
Failure to get full project team commitment	X	X		X
Failure to measure benefits		X	X	X
Failure to stimulate innovation				X
Failure to involve manufacturers and suppliers early	X		X	X
Failure to make critical decisions at the optimum time		X	X	X
Failure to apply S&P within an overall business or project strategy	X	X		X
Failure to change process from construction to manufacturing	X	X		X
Clients' view on Standardisation		X	X	
Use of Standardisation in renovation projects			X	
Lack of flexibility		X		

Table 2 - Concept matrix barriers of standardisation

The study by Gibb & Isack (2001) conducted interviews with 59 experts from significant construction clients and researched the drivers and barriers to the implementation of standardisation. The study shows that clients are generally optimistic about standardisation but do not know the exact consequences of implementing the concept. Furthermore, other barriers from the clients' view are the failure to measure the benefits and involve sub-contractors as early as possible in the project.

The research conducted by Aapaoja & Haapasola (2014) also performed a survey that focused the on challenges of practising standardisation. This study concluded that the following barriers are the central ones: 1) involving sub-contractors early in the project; 2) applying an overall strategy toward standardisation; 3) the failure to change the process from construction to prefabrication and to get a total commitment of the project team The four relevant studies all studied the barriers to standardisation. These barriers have implications for the design process developed further in this research. It is essential to consider these barriers when the research creates this process because by tackling these barriers, the implementation of the process will become more efficient. The barriers are gathered in Figure 7 to overview all the different barriers. This diagram divides four main aspects that allocate the barriers.

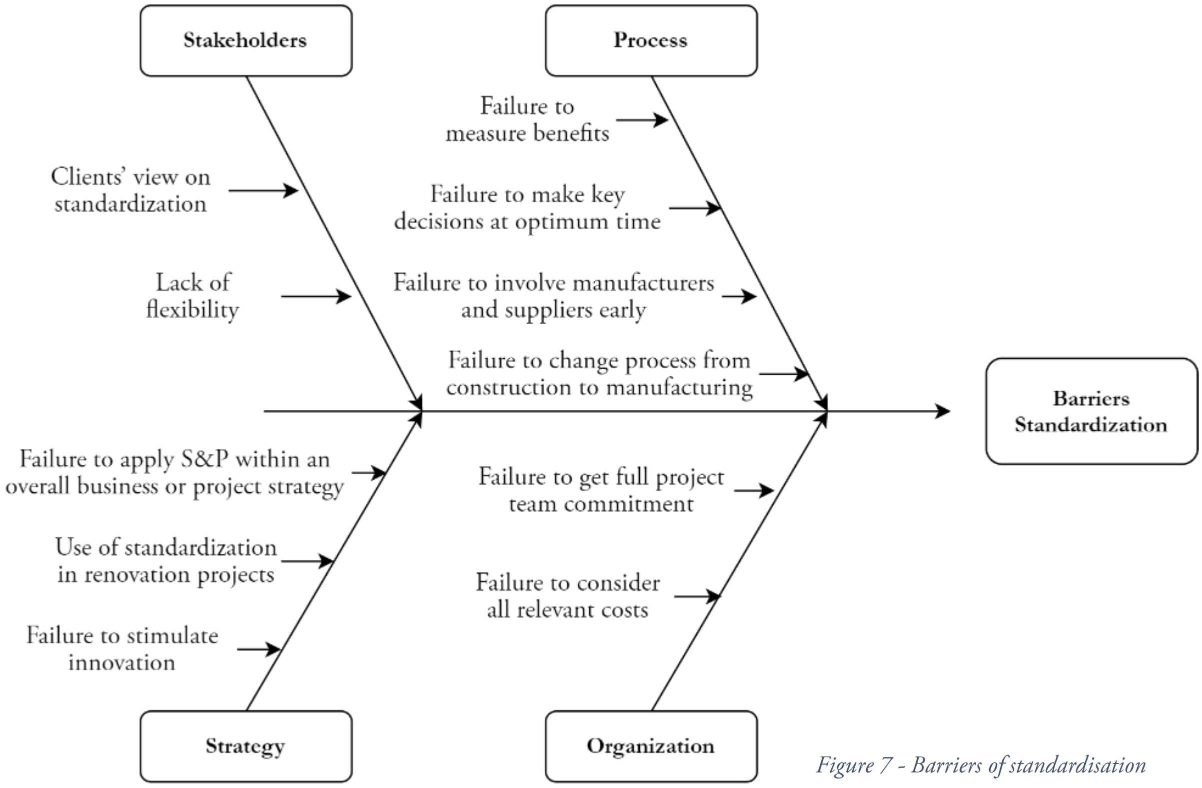

Figure 7 - Barriers of standardisation

These barriers bring up some challenges, such as the actions that the contractor should tackle to enhance standardisation.

2.3.3. Challenges

This section of the literature review focuses on the challenges of performing standardisation in the construction industry. This section reviews state-of-the-art literature to indicate the challenges of acting and applying standardisation in the construction industry. These aspects are actions that the contractor should tackle to promote the performance of standardisation.

Table 3 indicates the difference between the different literature publications and how these elaborate on the challenges for standardisation. This synthesis matrix is a summary of the difficulties noted. Aapaoja & Haapasalo (2014) describes four out of eight challenges, while Choi et al. (2020) only discuss one challenge. That is the challenge of quantifying standardisation, the most frequently indicated challenge. However, Choi et al. (2020) wrote a recent article about standardisation.

Challenges	**Related**	**Publications**					
		Aapaoja, Haapasalo (2014)	Pasquire, Gibb (2002)	Gibb, Isack (2001)	Gibb (2001)	CIRIA (1999)	Choi et al. (2020)
Quantification	Process		X	X	X		X
Planning	Process	X					
Flexibility	Product				X		
Contracts	Both		X	X			
Collaboration	Process	X					
Mindset clients	Product				X		
Mindset designers	Both	X					
Implementation	Both	X	X				

Table 3 - Concept matrix challenges standardisation

Quantification A challenge the industry is facing with standardisation is measuring the performance of standardisation in an organisation (Gibb & Isack 2001). According to Gibb (2001), the standardisation performance was rarely explicitly measured in practice and therefore based on assumptions and perceptions of clients and contractors. Thus, the quantification of standardisation should be studied, or at least tried to be made clear. For instance, Choi et al. (2020) made a decision-making model evaluate if a project would profit from standardisation. This model assesses if a project is viable for standardisation. This challenge focuses on product and process. It should be clear what standardised means and why to make it quantifiable.

Planning Currently, according to Aapaoja and Haapasalo's (2014) research, the relevance of front-end activities and precise planning is not always well known. These two aspects emphasise increasing the buildability of final products, which will result in more standardised processes.

Flexibility An issue the industry is struggling with is the interface between flexibility and standardisation (Gibb, 2001). This interface where the industry has to facilitate the architect and client with variation possibilities in design and where the industry wants to implement more uniformity is still a challenge the industry is facing. It is a tension that is difficult to resolve because there are opposite interests. These interests are from one side based on current processes, habits, and more traditional ideas, while the other considerations are focused on more innovative ideas of the performance of standardisation.

Contracts Another challenge that arises is warranties and their conditions. Currently, not all contracts enable standardisation, which is elaborated on before in this review. Furthermore, Pasquire & Gibb (2002) indicate that contractual arrangements influence how the contractor can implement standardisation, process- and product-related.

Collaboration One of the issues that causes friction in implementing standardisation is the current fragmented collaboration in the supply chain (Aapaoja & Haapasalo, 2014).

Mindset Client With the implementation of standardisation, it comes to clients' minds that standardisation means standard and, therefore, boring (Gibb, 2001). That implies that clients are more hesitant when standardisation is the new, used concept. For instance, the design and buildings of McDonald's could a client see as boring and standard. Currently, more and more projects apply standardisation with not a boring design.

Mindset Designers Another challenge with mindset is that designers see projects still as unique. Therefore the design and engineering processes are performed according to the traditional project life cycle. Designers do not understand and know the benefits of standardisation which has a lagging effect on implementing Standardisation (Aapaoja & Haapasalo, 2014). The value of standardised processes and products is not understood.

Implementation According to Aapaoja & Haapasalo (2014), an issue is that the current design processes do not enable and support a form of standardisation. Therefore the use of standardised products and processes is low. Both aspects should complement each other to introduce standardisation in an organisation successfully. The question arises: 'what should be the first to standardise?' the product or the process. According to Aapaoja & Haapasalo (2014), the procedures should initiate the possibility of designing and constructing standardised elements. Therefore, standardising and organising the design process of standardised construction elements could be seen as the action to perform. When the organisation applies both aspects, the benefits of standardisation will arise. Aapaoja & Haapasalo (2014) state that using a holistic view is the best to change processes towards standardisation. The contractor should create a new context to perform standardisation in the organisation. Furthermore, the implementation process should not go too fast because employees should get time to adapt (Aapaoja & Haapasalo 2014).

2.3.4. Benefits

The implementation and the use of standardisation enable benefits for the organisation, which this section reviews. Furthermore, Figure 8 shows the benefits in a more organised summary. Reviewing the benefits of implementing standardisation clarifies how it influences organisations and how these could be influenced by applying standardisation.

These studies indicated precisely the benefits of performing standardisation—nonetheless, more studies elaborate on the benefits of standardisation, such as Gibb (2001).

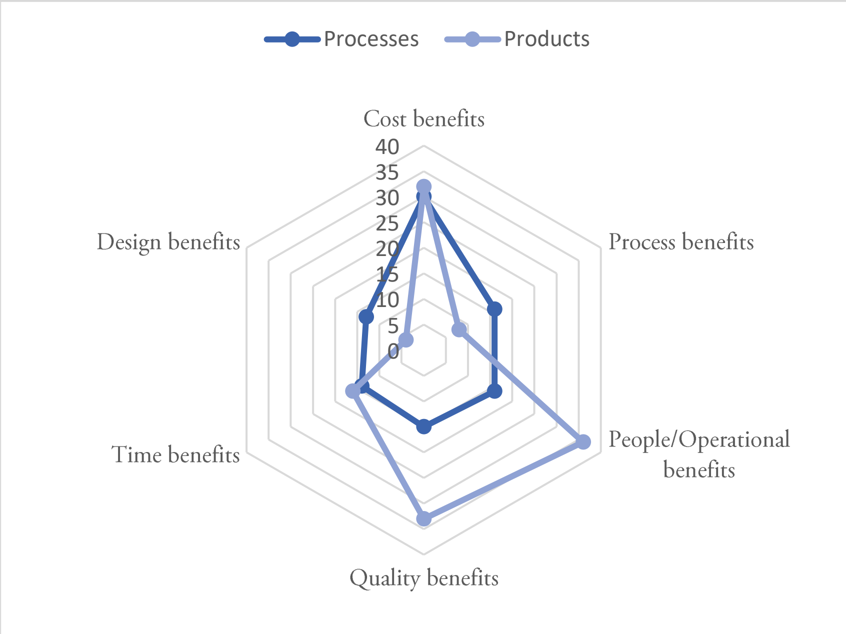

Figure 8 - Benefits standardisation - source: Gibb & Isack (2001)

Process benefits	Product benefits
Rationalised interfaces	Tried and tested track record
More predictable on-site activities	Increased productivity through familiarisation
Increased productivity through familiarisation	Reduction of waste
Less waste, noise, dust etc.	Use of the same components on follow-on projects
Minimised disruption	Available replacement parts
Better able to cope with congested sites	Greater certainty of the completion date
Statistical reduction in H&S and environmental hazards	Minimised overall project time
Improved quality control	More predictable lead-in times
Improved certainty of completion date and cost	Predictable quality & performance
Fewer on-site operations, personal & duration	Off-site inspection

Table 4 - Overview of benefits of standardisation - source: Pasquire & Gibb (2002)

Gibb & Isack's (2001) study indicates the benefits of standardisation to meet clients' requirements in six general aspects, shown in Figure 9. This Figure distinguishes two main aspects of standardisation: processes and products. The study concludes that the client embodies more benefits than concerning processes with standardised products. That is obvious, given that the client will see the tangible products while the processes are not necessarily concrete or visible to the client.

The study of Pasquire & Gibb (2002) has defined the benefits stated in Table 4 by distinguishing the process and product. This table gives an overview of the benefits indicated by the research, which the study bases on interviews with 25 experts. Furthermore, this research performs a case study on an existing project. The main benefits arise in improving health & safety, productivity, more value for money, better predictability of costs, and time.

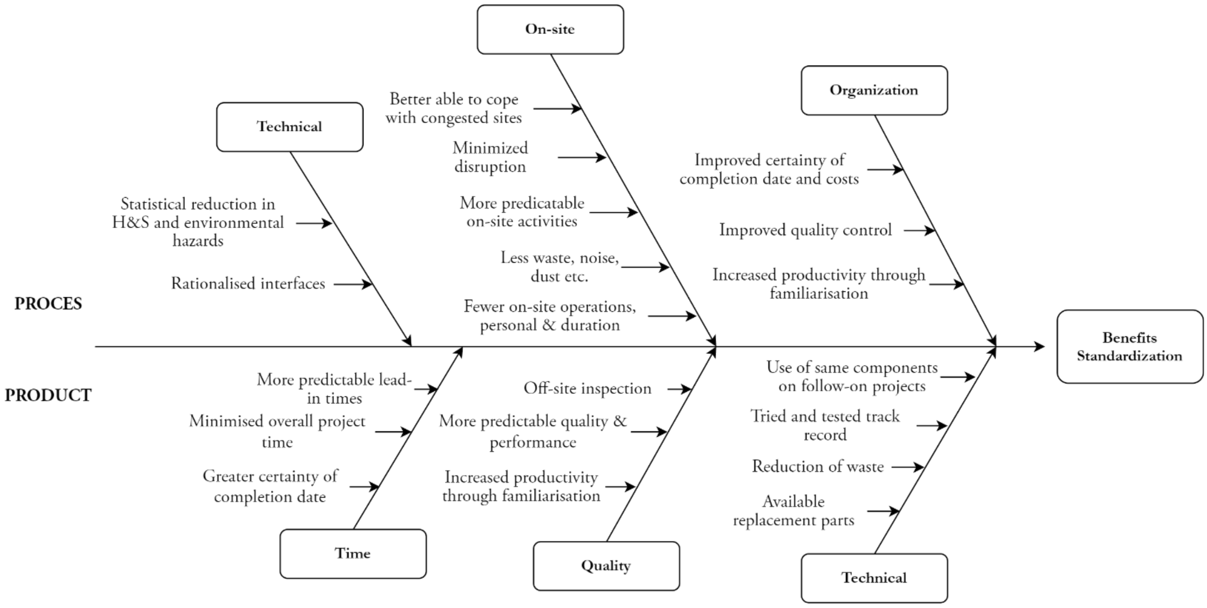

Figure 9 - Overview benefits standardisation process and product – source: Gibb & Isack (2001), Pasquire & Gibb (2002)

When both overviews are combined, the review indicates an overlap in the six benefits stated by Gibb & Isack (2001). These are more general, while the benefits for processes and products differ in the study of Pasquire & Gibb (2002). There is a difference in the studies both articles execute while conducting interviews and surveys, using a case study to investigate standardisation challenges. However, Figure 9 gives an overview of the benefits of standardisation. With these benefits, it is clear which aspects are beneficial for the implementation and application of standardisation in the construction industry. The development of the standardised design process incorporates these aspects.

The benefits will transform into more general advantages. Therefore, this study executes a small literature review focused on the advantages of the implementation of standardisation. Advantages indicate the aspects that enable benefits and are more also general groupings of factors that are positive consequences of the concerning policy. These will focus on the positive effects of implementing standardisation.

Then, the concerning elements or processes that are standardised will have a more durable and sustainable approach and lifespan because the quality of these elements or processes is more guaranteed. It is more guaranteed as the contractor knows better how the standardised elements or processes perform during the lifespan, which will result in more durability and sustainability.

By performing standardisation, the company will have a more competitive advantage over their competitors because, with standardisation, the company can better focus on and meet the client's requirements. Furthermore, the company can guarantee better performances with more durability and sustainability, generating more competitive advantage.

2.3.5. Conclusion

This section discusses the definition of standardisation according to the state-of-the-art literature, which describes the meaning of standardisation in the construction industry in six aspects. Based on the literature, these aspects are: 1) rule, norm; 2) repetition; 3) systematic approach; 4) construct; 5) successful history; 6) shared structure.

Standardisation's benefits focus mainly on increasing productivity, quality, safety, and financial feasibility. Here, the study translates the benefits to process and product benefits. However, the main benefits are the same for the two perspectives.

Multiple challenges of standardisation are identified, which are: 1) quantification; 2) planning; 3) flexibility; 4) contract; 5) collaboration; 6) mindset clients; 7) mindset designers; 8) implementation. These challenges are current practical objections to overcome, which form the bases for developing the standard design process for utility building elements.

Many barriers block the performance and implementation of standardisation. These arise from stakeholders' perspectives, processes, strategies, and organisation. These are more soft perspectives from another approach, while the construction industry focuses more on the challenging, technical perspectives. The industry must focus on soft skills and attitudes to organise the business to enhance standardisation.

As a result, standardisation is a concept that the contractor can apply in different forms in the industry, focused on processes and products. This study focuses on standardising the design process of the utility building industry elements. The fast-changing world enables more industrialisation and standardisation of the industry. Moreover, the focus is either on a more sustainable industry. Besides standardisation, the design concepts of parametric design and modular design help to meet the changing needs. These two concepts focus on flexible designing and designing circular, which is needed to create extra value for the industry. Therefore, the design concepts are reviewed in the following paragraphs and related to standardisation.

2.4. Parametric and Modular Design

Besides standardisation, the industry applies parametric and modular design concepts more and more. This chapter will focus on these two concepts and how they relate to standardisation. Both concepts can use according to a method that makes it possible to design with a fixed number of design alternatives. With the rise of sustainable technologies in the construction industry, the need to create according to new sustainable methods, which enable explicitly modular construction, has increased. These concepts are relevant for standardisation, seeing that standardisation implies the refocus of design freedom in simplifying the number of design choices. Figure 10 indicate the framework this study is researching. Standardisation is an approach and modular and parametric design concepts in this study.

Both concepts will be discussed and elaborated on regarding their definition and relation to standardisation. A synthesis matrix is developed based on aspects that define the concept. Afterwards, these aspects of the concepts can be reviewed and compared to each other to see their relations.

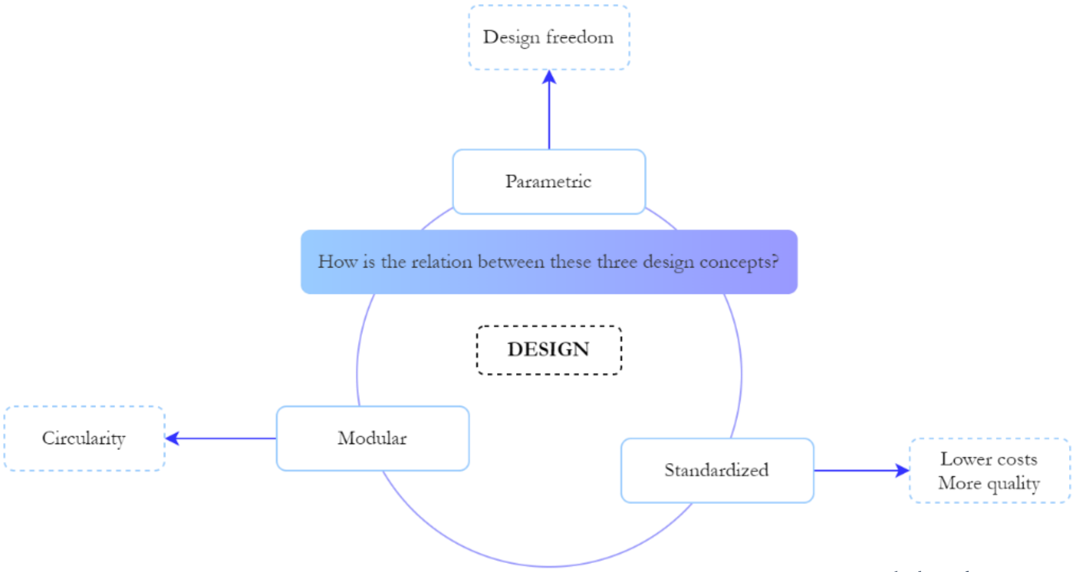

Figure 10 - Framework three design concepts

2.4.1. Review parametric design

Parametric design is a concept implemented more and more in construction. It is a concept that enables digitalisation in the construction industry and design according to many design possibilities. These design parameters can be a form of standardisation before performing parametrical design. This relation is elaborated further in this section.

Different studies did research towards parametric design. Monizza et al. (2016) developed a generative algorithm tested in a case study on the glued-laminated timber industry. Monedero (2000) research considered the current situation in architectural designs and how the industry uses 3D tools in these processes. This study focuses more on the architect's view and the application of tools that enable 3D generative techniques. Another study, Hudson (2010), focused on strategies for parametric design. The practical side of parametric design is covered based on different case studies. Based on observations, the study investigates potentially overlooked aspects.

Monizza et al. (2016) state that parametric design is a generative design process that aims to find the optimal possibilities for a design problem based on standardised design parameters and processes. There is a relation between the designed element and the generation of the design itself.

Monedero (2000) defines parametric design as a demarcated concept based on many parameters that enable the design. Additionally to this definition, the study indicates that it is not clear how parametric design and computational generative design relate to each other.

Hudson (2010) divides the concept into two terms: parametric and design. Then, the study points out that the term parametric implies parameters, leading to "para", which means metron and, therefore, measure. Thus parameter can be seen as a specific, measurable factor. The other term indicates the process of developing and drawing a solution. It is a task which concerns finding a solution to a problem. Overall, parametric design describes the computational process of designing based on relationships between different design aspects.

The study of Banihashemi et al. (2018) focuses on the relationship between modular construction and parametric design to decrease the amount of waste in construction. The study defines parametric design as using artificial knowledge to design different possibilities based on computer attributes, including rules to structure the results. Therefore, the following four main aspects indicate the design process assumptions: 1) the start with conditions and parameters; 2) a generative design method; 3) designing variations; 4) choosing the best design;

The research of Abrishami et al. (2013) focuses more on the integration of parametric design and BIM in the AEC industry, which relates specifically to this. Abrishami et al. (2013) define parametric design as an approach that 1) parametrises the design concerning BIM; 2) the computational aspect; 3) how parties can apply generative designing.

A synthesis matrix is created based on the reviewed literature and the five main aspects that define the parametric design to describe parametric design thoroughly. Each aspect is defined and elaborated on why that relates to parametric design. Therefore, this research uses the following definition: "*the design of a project based on a fixed amount of design parameters enables generative computational design based on the input of these parameters and demarcates the design.*"

Generative: the parametric design can be performed by programming generating multiple solutions based on the variations of the parameters that enable more different design options, whereby the goal is to find the solution that satisfies the problem.

Standard parameters: Different designs can be developed based on many design attributes. These design attributes imply standard parameters. For example, this could be multiple variations in the materialisation of a pipe or different variations in the diameter of the tube. In these cases, the parameters are materialisation and the diameter of the pipe. In section 2.5 on the page 42, parameters are in-depth discussed.

Standard process: because the parametric design bases the concept on fixed design phases, the design process is standard.

Demarcated: the design developed is within boundaries by applying parametric design because the parametric design bases the concept on fixed parameters and a fixed process. Determined in the design context is possible according to the standard parameters' ranges, i.e., defined variations.

Computational: an essential aspect of parametric design is computational knowledge. Parametric design enables generative designing by computers.

Publications	Aspects Parametric Design				
	Generative	Standard parameters	Standard process	Demarcated	Computational
Hudson (2010)	X		X		X
Monedero (2000)	X	X		X	X
Monizza et al. (2016)	X	X		X	X
Banihashemi et al. (2018).	X	X	X		X
Sepehr et al. (2013)	X	X			X
Wortmann & Tunçer (2017)	X	X		X	

Table 5 - Synthesis matrix review Parametric Design

This matrix, Table 5, indicates how the referred literature defines parametric design. Therefore these five aspects are revealed. The review shows that the generative factor of parametric design is defined in each study and is, hence, the most relevant definition aspect. Another relevant aspect is standard parameters, which are needed to design generative.

The review indicates relations between standardisation and modular design. The following aspects can be part of these connections between the concepts.

- The design is based on a fixed number of parameters with the parametric design, indicating standardisation because these set parameters mean a form of standardisation.
- The design process with parametric design is very determinate, which also indicates a form of standardisation. The chosen approaches and methods determine some process standardisation. These selected approaches and methods can be identified as standard when the parametric design is the design method.

2.4.2. Review modular design

This section discusses modular design. Based on a literature review, the definition of the concept and how it relates to standardisation. Modular design is a concept implemented more and more in the construction industry since modular design offers more value to construction projects and enables a more sustainable design (Generalova et al., 2016).

Many studies researched modular construction. Lawson, Ogden & Goodier (2004) researched different aspects influenced by modular building in the construction industry. Furthermore, the research elaborates on specific examples and designs. This study has a more practical approach. Generalova et al. (2016) analysed a case study where different cases are discussed based on applicability. The study of Choi (2014) researched the concept and conducted a survey.

Lawson, Ogden & Goodier (2004) define modular construction as three-dimensional and prefabricated units in a factory, which are then delivered on-site as some of the leading construction elements of the project.

Choi (2014) defines modularisation as the preassembly of a complete system in an off-site location and transporting it to the construction site. Furthermore, the system can consist of more minor elements that should be constructed on-site.

Generalova et al. (2016) define modular construction as the off-site prefabrication of modules. It combines high-tech technologies based on rapid construction methods. Furthermore, the concept divides into two separate parts: the definition of prefabricated elements and the use of 3D elements.

The study by O'Connor et al. (2014) establishes that modularisation is a new concept even though much research elaborates on this concept. In that research, they use the definition of Haas et al. (2000), which is the prefabrication of elements that are constructed off-site and transported to the site for construction. This definition follows in mainlines the same reasoning as Choi (2014).

The reviewed literature regarding modular design translates to the following synthesis matrix, Table 6. The matrix develops an overview based on five aspects of the literature review. These five aspects define modular design. Therefore, this research handles the following definition: "*designing with the focus on prefabrication of building components/element/modules and then are delivered on-site, based on 3D-dimensional assumptions with innovative design methods.*"

Prefabrication: this term is the central aspect of modular design, which indicates the realisation of elements, and modules, in a location somewhere other than the construction site and constructs over there.

Modules – units: these modules are the parts that the contractor designs modular. Modular design often refers to larger modules and units of buildings.

Delivery on-site: after prefabrication in a factory, the contractor transports the modules to the building site. This delivery on-site is an essential aspect of modular design.

Innovative design methods: modular design and construction develop with innovativeness to design and construct with this concept.

3D – dimensional: With modular design performance, the designer designs the solutions into 3D-dimensional units or elements.

Publications	**Aspects Modular Design**				
	Prefabrication	Modules - units	Delivery on-site	Innovate design method	3D - dimensional
Banihashemi et al. (2018).	X	X	X		X
Choi (2014)	X	X	X		
Generalova et al. (2016)	X	X		X	X
Haas et al. (2000)	X	X	X		
Lawson, Ogden & Goodier (2004)	X	X	X		X
Wuni, Shen (2020)	X	X	X		

Table 6 - Synthesis matrix review Modular Design

According to the synthesis matrix, prefabrication is the central aspect that defines modularisation. Therefore, this review states that prefabrication comes with modularisation. The modules are an essential aspect of the definition of modular design. The delivery on-site of modules is related to the prefabrication, which the contractor does in a conditioned environment.

Furthermore, the review makes the following differences; modular construction and modularisation have different angles to approach potential relations with standardisation. Therefore, this review states that modular construction and modularisation have come the same in this study. Additionally, based on the discussions of literature relating to modular design and standardisation, the following relations are discussed. These relations will be more elaborated in the next section of this chapter.

- There could be a relation between modular construction and standardisation from the point of view of prefabrication. For performing prefabrication, the designer involves the concepts of modularisation and standardisation.
- By constructing modular, standards become a more valuable factor because the interface between elements or modules should be coordinated, i.e., standardised. This standardisation occurs by defining design conditions, criteria or rules.
- The modular design has the same benefits as standardisation.

2.4.3. Relations between standardisation, parametric and modular design

According to the conducted reviews on a parametric and modular design, the research distinguishes the following connections between these concepts and standardisation. Overall, the study divides these relations into more process and product-focused considerations, Where Figure 10 gives an overview of the general connection between the three concepts.

Process relations:

Standardisation relates to parametric design based on the process relations: first of all, parametric design's performance comes to a standard process. This process ensures a norm to follow when applying parametric design. After performing this process, generative can be designed based on the developed parameters. Furthermore, standardisation ensures the implementation of parametric design. Parametric and modular design apply high-tech design technologies that perform according to a process that incorporates standardisation. Both concepts use a common construct as assumptions for designing modularly or parametrically. This common construct is standardisation enables the performance of modular design because, for the implementation of the prefabrication of modules, the production process needs repetition. Furthermore, this prefabrication process has repetition, shared structure, and systematicity characteristics. These relate to standardisation.

Product relations:

The design needs to have defined conditions to understand why and how to design by applying the boundaries by using parametric design. These boundaries represent the parameters to create in the process. Furthermore, there is a refocus of the design during this process, which influences the design freedom. Modular design and parametric design relate from a product perspective. Both concepts incorporate some boundaries in the design of an element. Furthermore, the design of the components focuses on 3D dimensional generative and computational assumptions, which implies the concepts relate based on these design assumptions. Modular design is standard by standardising the interfaces between modules based on standard design conditions.

Figure 11 shows that standardisation stands above or around the two other design concepts. When both or one of the two design concepts is applied, the standardisation comes with the design by defining design criteria or conditions, i.e., design rules, to design modular or parametric. In other words, standardisation comes with modular and parametric design.

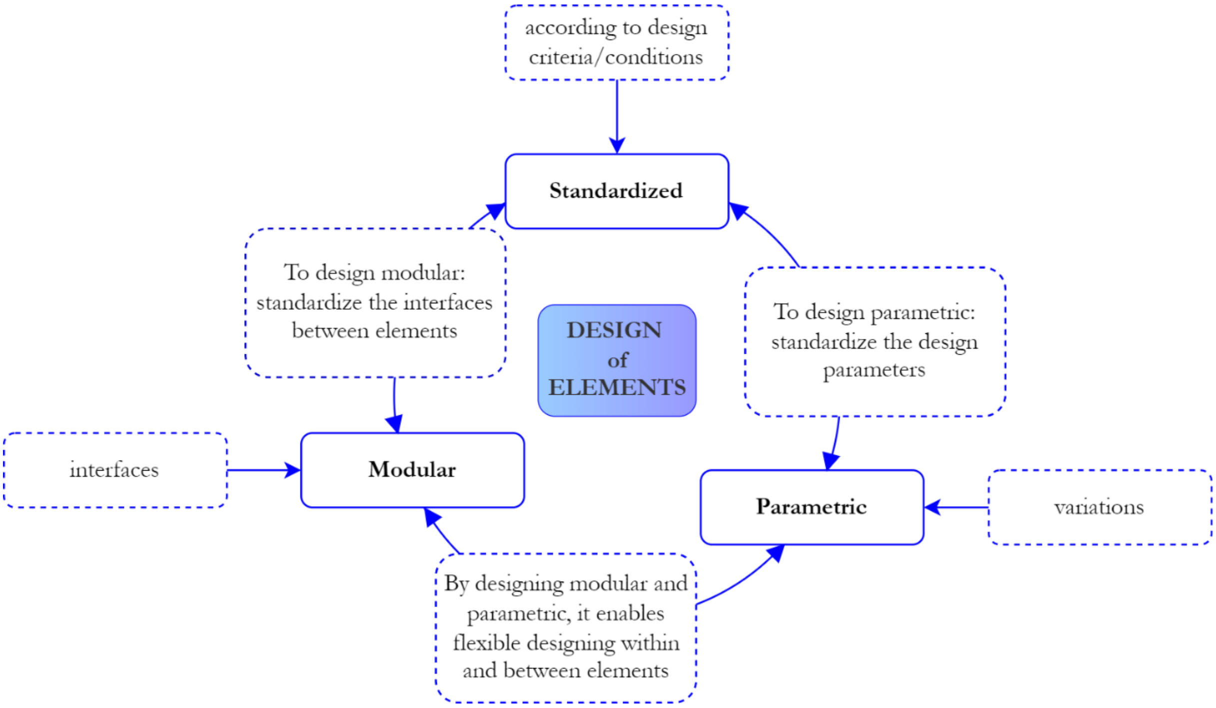

Figure 11 - Relation between standardisation, modular and parametric design

The figure combines the three concepts, which enhance the industry. However, the designer can apply concepts separately. Conversely, the other two concepts are then also involved in some manner. When the contractor standardises a design, the design choices refocus, and modular or parametric design performance becomes more straightforward. With the parametric design, standardisation takes place for developing the parameters. And with the application of modular design, interfaces are standardised according to the defined design conditions and criteria. The relation between the concepts is definitive in most applied cases tangible and translated to the above-shown figure.

Relation with challenges of standardisation

The contractor can solve the challenges of standardisation by designing with these three concepts because the combination of the concepts leads to design freedom as well as standardisation and therefore influences the challenges positively. By focusing on the strong aspects of the concepts, the combination can enhance and influence these challenges. For instance, parametric design positively influences the challenge of flexible designing, and standardisation can influence the planning of production and assemblage. Furthermore, by developing and designing elements with these concepts, the contractor should execute long term collaborations with other organisations. Project contracts, mindset and implementation are challenges that come with other aspects of standardisation, which this study focuses on in the interview chapter, chapter 3.

2.5. Design parameters

Concerning the standardisation of the design process, the design parameters can be standardised parallel to the design process. The design parameters are aspects that indicate the design, which will be more elaborated in this chapter. Based on the axiomatic design concept (Rauch et al., 2015), these design parameters will be discussed and reviewed.

The design parameters are the attributes that give completion to the design of the utility building elements. Thus based on requirements, the parameters fulfil the needs of the client.

Axiomatic design is a concept of the interplay between the customer's ideas of what the design should be and how they interpret the result. This concept, which Suh developed in the 1970s, is divided into four aspects. All different designs, from processes to systems or organisations, can be performed according to this concept and fit these four aspects (Rauch et al., 2015). The physical and the process domains from the customer domain to the functional part.

First, in the customer domain, the attributes the customer tries to achieve with a new design are represented, i.e. customer requirements for the design. Then, these customer requirements are specified in the functional domain by functional requirements (F.R.s) and constraints (C.s). Functional requirements are independent requirements that include the functional needs of the design. Design parameters are indicated in the physical domain to set up these functional requirements. Design parameters (D.P.s) imply the physical attributes that cover the specifications of the functional requirements. Then, in the end, the design parameters are converted to process variables that indicate the attributes that make the design parameters viable. Figure 12 indicates these four phases as elaborated here.

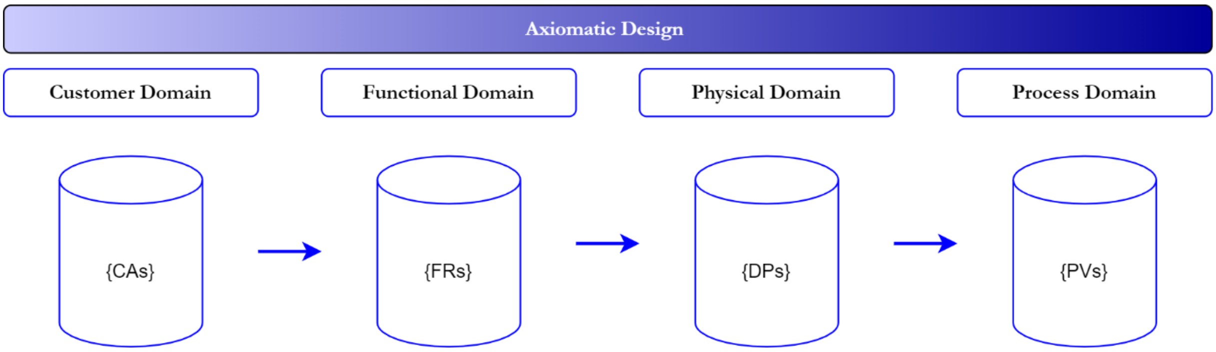

Figure 12 - domain structure Axiomatic Design

It makes it better to approach this development of this standardised design process in an organised manner because the idea incorporates a structured method that involves the design and process attributes. Therefore, this research employs the concept of standardisation of the design process during this research. The following example elaborates the parameters where a window applies the idea to identify how it performs.

CA: the customer wants protection from outside, a view and daylight.
F.R.: daylight in the form of 10.000 lux.
D.P.: a window of glass that has dimensions: 1000x1500mm
P.V.: design, develop, order, construct

Figure 23 - Example application axiomatic design

Another aspect that comes with the performance of the axiomatic design is the use of two axioms. The designer uses these to guide through defining these parameters. Furthermore, the axioms help with evaluating if the specified parameters are suitable. Axiom 1 is The Independence Axiom, which implies the designer should apply the defined parameters to the design without any form of affection between each other. Then the second axiom is The Information Axiom, which implies using the parameters that have minimised information. The parameter to achieve is the one with minor details.

Besides axiomatic design, this review researches parametric design, and that is why the following paragraphs discuss the creation of a parametric model. The development of a parametric model involves translating the design problem into specific design parameters, which will be one of the main tasks during the standardised design process of utility building elements. Therefore, the study reviews this process of indicating the design parameters according to the parametric design approach.

When the design of an element starts, the first main task is to define the design problem, which translates to parameters for the design of that concerning problem. However, these parameters should be identified in some structure.

1. Function related parameters are the main addition to the concerning design.
2. Structuring related parameters, more focused on the design's material-related completion.
3. Behaviour related parameters identify the achievement of the functional parameter.

This distinction of design parameters should be realised thoroughly during the design of an element because the choices made during that design process are dependent on the design problem. This process relates to the information exchange discussed earlier in this literature review, which implies the exchange of design information during the translation of the design problem into possible parameters according to the above-elaborated structure.

Significant to indicate is the level of application of this structure of parameters to design choices made. In this study towards standardisation of the design process of utility building elements, this structure applies to each material application in the whole design of the developed element. The following Figure 14 clarifies the reasoning of this section by using the different parameters.

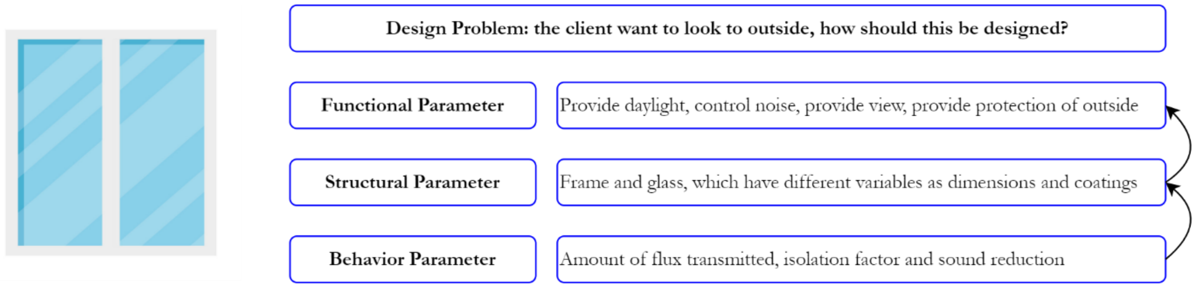

Figure 14 - Example application parameter structure

These parameters enable the creation of different design alternatives that meet the design problem. According to Hudson (2010), creating other options is the main task of exploring different design solutions. However, this exploration is within the boundaries, the values of the parameters defined during the design process.

This section focused on the structure of parameters for designing an element, which is an essential aspect of applying parametric design in a standard process. Because this research focuses on developing a standard process the next section focuses on the more developing approach to that standard process.

2.6. Information Delivery Manuel (IDM)

This section focuses on the Information Delivery Manuel (IDM) due to the purpose of this study is to develop a standard design process for developing standard utility building elements. Therefore, it is essential to review, indicate and describe the relevant literature on this research subject. The study uses this gathered literature and insights to develop an IDM of the design process of utility building elements. IDM is the chosen reference for developing the process map.

2.6.1. What is IDM

The industry developed IDM due to the number of issues raised with the performance and implementation of Industry Foundation Classes (IFCs). These issues focused on information flow difficulties with the rise of Building Information Modelling (BIM) using IFCs (Wix & Karlshoj, 2010). The IFCs performed as support for meeting the business requirements during the whole project life cycle. However, there was a gap in how to deliver the information contained in IFCs. Thus, IDM is developed as an approach to describe business processes and the necessary involved information used by specified actors.

2.6.2. BuildingSMART

BuildingSMART (Wix & Karlshoj, 2010) developed this IDM approach, an international organisation that enables standards within the construction industry. The organisation focuses on facilitating digital workflows with open international standards based on BIM. Their goal is to generate productive, efficient processes and share these openly with their global community.

2.6.3. Business Process Modelling Notation

With the use of IDM comes the use of BPMN as process notation. It is preferred to use BPMN because it deals with some issues that occur in previously used notations and is currently widely adopted by business organisations. This notation rise from the notations of UML EDOC Business Processes, IDEF, UML Activity Diagram, ebXML BPSS, RosettaNet, LOVeM, Event-Process Chain, and Activity-Decision Flow Diagram. Thus, BPMN is a general comprehendible, often used notation filling the gap between process design and implementation.

BPMN adds some structure and approaches to the IDM approach. The following rules are indicated as necessary for BPMN in the IDM approach.

- A BPMN shows an exchange requirement in a specific lane as a particular object in the information lane.
- This information lane is a specific lane.
- A BPMN defines a specific actor for each activity, and each actor has his lane.
- A whole process map is applied in a single 'pool', implying that one pool' can indicate one organisation and that an actor is a part of that organisation.

2.6.4. IDM Components

The IDM consists of some main components that are the process map. Figure 15 indicates how the three main components relate to each other.

1. Process map helps to understand the operational flow and how to do these tasks. The notation used in a process map differs. With the application of the IDM approach, the study uses the BPMN notation.
2. Exchange requirements are the components that connect process and data. It implies the information exchanged during the process, focusing on meeting the requirements of information exchange between two methods.

3. The functional part consists of the actions that the concerned stakeholder should undertake that are needed to carry out the process. This action consists of information that the stakeholders develop further and contains a specification of information they exchange.

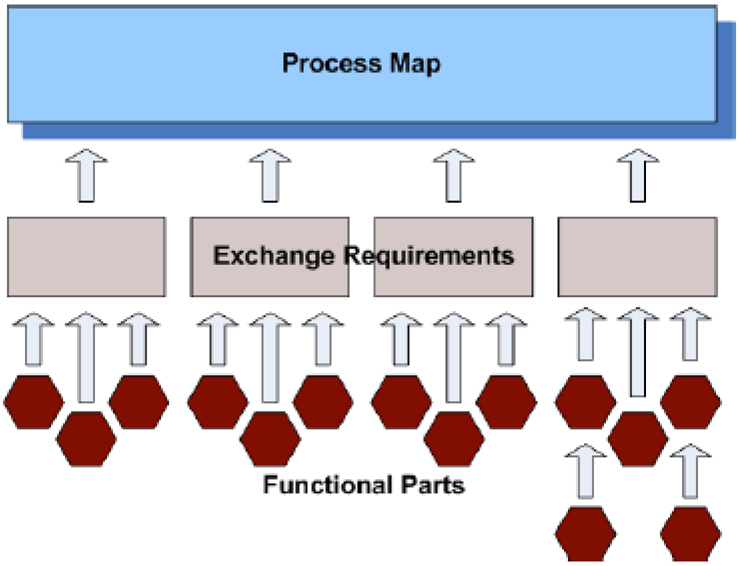

Figure 35 - IDM Components (source: Wix & Karlshoj, 2010)

2.6.5. Purpose of the process map

The process map connects the exchange requirements and the business process. This process map fulfilled by IDM tries to combine all relevant information of the developed business process and enables thereby advantages of process improvement and information sharing (Wix & Karlshoj, 2010). Furthermore, IDM is an approach to developing new methods consistently and is currently an often performed process development approach (Wix & Karlshoj, 2010).

A process map has specific goals by itself. The following purposes are essential:

1. There should be a goal;
2. It should have particular input;
3. It should have particular outputs;
4. It should use a form of resources;
5. There should be activities to perform;
6. The process map may influence more than one organisational business;
7. The process map creates a state of value for the client;

With the application of the IDM approach, the purpose is also to indicate and describe the exchange requirements. A process map is performed for quality assurance and business process efficiency (Aguilar-Saven, 2004). These two primary purposes are the general assumptions to perform and develop a process map.

2.6.6. Development of IDM

According to Wix & Karlshoj (2010), a company should undertake the following actions to develop a structural IDM (. The literature divides the development into five main tasks, where each task has its specific goal.

1. Propose IDM

The first task is to define the purpose of the process map. Therefore, the following sub-actions are identified and elaborated.

Identify scope: here, the boundaries of the process are indicated and elaborated.

Identify resources: in this action, the stakeholders and components involved in the process are identified.

Fixing the development route: with IDM, three types of developmental pathways can be applied. These are specifically described below. This action should be determined which type is used to develop the process.

Project plan; this plan describes the management of the development of the process. It tells the tasks that need to be conducted, sets the deliverables, and indicates the resources required.

2. Develop IDM
As described in section C, there are three types of development approaches for IDM.

Process Discovery and Data Mining: This is the most often used development approach. The process does not yet exist in this approach, and the stakeholders, exchange requirements, and software should be identified.

Business Rule Localisation: In this approach, the exchange requirement already consists but the location of how and where it should be applied is not yet explicitly defined.

Reverse Engineering: This approach is based on the thought that the software already consists of dealing with the information. But that it is not clear how these two are connected. Thus, the software is the starting point for developing the process in this approach.

3. Define concepts and terminology
It is crucial to define and elaborate on all the proceedings, concepts, and terminology applied and used in the process map during the process map development.

4. Publish IDM
When the IDM components are finished, these should be published on the IDM website to make this process widely available as a new standard.

5. Check IDM
Other IDM developers should check and review the proposed process, exchange requirements and functional parts. That will ensure the extra validation of the process.

2.7. Conclusion

This study aims to summarise and combine state-of-the-art literature that contributes to the knowledge of standardisation in the utility building industry. Moreover, this study discovers recommendations and insights for developing a standard design process for utility building elements and indicates relations between design concepts that influence the designing of these utility building elements. Therefore, this literature review meets the goals defined for this study by answering the research questions of this review.

This combination of knowledge consists of the project life cycle and relating challenges, involves standardisation with the relating benefits, barriers and challenges, and the review of parametric and modular design in combination with standardisation and the concerning design parameters. Standardisation and the utility building industry, the AEC industry, can be a successful combination.

This literature study towards standardisation in the utility building industry and, more generally, the construction industry contributes to a research gap. Because this study combines all-important scientific knowledge around standardisation, contributing to this gap. Seeing that the reviewed literature contributes specifically to the understanding around standardisation, the combination of all knowledge increases the reason to implement this gained information in the industry.

From the literature review, combining standardisation with parametric and modular design makes it possible to design more efficiently and implement standardisation in a better approach. While there is still relatively less prior research conducted on these relations, this combination can enhance the industry, specifically the utility building industry, because the utility building industry is an industry with a significant variance in material, appearance and shape. At the same time, some components and elements are so generic that these can be more standardised, with the performance of parametric and modular design to enhance quality, productivity, safety and decrease costs. The next chapter develops a standardised design process to design these elements.

This study has some limitations; first, because the relation of standardisation with parametric and modular design is studied less in prior research, this part is studied more conceptual. Therefore, a recommendation is to investigate these relations between the three concepts to gain knowledge of how these concepts can enhance each other. Furthermore, this research did not include some other concepts related to standardisation due to this study's approach and purpose. These other concepts are relevant if there is a determined condition, the developed design process. So, after this research, these other concepts like DfMA and LEAN can be studied and add relevant knowledge and insights.

In conclusion, this review towards standardisation states that standardisation can benefit the whole industry and contractors constructing buildings. Standardisation can enhance productivity, quality and safety and decrease costs, as shown in the theoretical framework based on this review. This review made the next steps towards a more standardised utility building industry to improve the overall quality and efficiency.

3. Qualitative research: interviews

This chapter focuses on the structure and results of the interviews conducted for this research.

3.1. Motivation

For this study towards standardisation in the utility building industry, semi-structured interviews are chosen as a research method to gather relevant data for developing a process map for designing utility building elements. Semi-structured interviews help to combine the scientific field with the practical working field, which should implement the results of this research. That is also the strength of this research because that enables more accessible and better implementation of the results of this research.

The goal is to know the current standardisation situation in the industry, from contractors to subcontractors or process managers, and to see how that relates to a parametric and modular design. Furthermore, to get insights into how current processes are structured and which influences are essential during the design of utility building elements.

3.2. Hypothesis

The following hypothesis stated is used for conducting these interviews for these interviews.

To identify the essential issues of standardisation of the utility building industry, the current perspectives in the industry and practical insights are related to the literature study conducted beforehand. The expectation is that the main results of the interviews will be in line with the literature review. To be more specific, the interviews will have a more practical approach, while the literature review will generate a more conceptual approach.

3.3. Interview set up

In this section, the interview setup is discussed and elaborated on. For developing the interview guide, this study performs the structure of Rowley (2012). This enables to set up of the interviews structurally and according to scientific argumentation. After this elaboration, the interview questions are explained and explicitly reasoned why the questions are relevant.

This study chose interviews and not a questionnaire because understanding, opinions, and insights are needed to develop the standardized design process to answer the research questions. The interviews also have a more explorative focus because this is an explorative study towards standardisation in the utility building industry. Therefore, there are two reasons for these interviews:

1. Interviews are relevant for gathering data about phenomena, understanding opinions, insights about processes and products, and reasoning behind choices made in the industry, according to Rowley (2012).
2. Furthermore, the main objective of these interviews is to validate and compare the literature review with the current situation in the industry. The development of the standardized design process can be related based on both approaches to see and study the relation between scientific literature and the practical field. This has as advantage that the proposed process will be scientifically motivated and fit the current construction industry.

These interviews are conducted individually and not in group form. That gives the possibility to focus on the expert and his/her specific input and select the expert's function in the industry.

The interviews conducted for this explorative study will be semi-structured because it enables the possibility to gather data based on various questions. Structured interviews are too similar to questionnaires and do not enable the opportunity to go in-depth in an answer of an expert, which could contain precious information. Conversely, unstructured interviews do not give enough direction to gather the data that should answer the questions and compare with the literature review.

The questions stated in the interviews are based on theory gained during the literature review. Furthermore, the questions would also be iterative during the first interviews when finalizing the research questions. That enables to make some iterative cycles to optimize the questions to get better results that fit the study and the goal of the interviews.

There are about 60 minutes needed for an interview to answer all the defined questions. Furthermore, there should be around 15 interviews to get a well representative conclusion. However, the most crucial aspect is to have interviewees from other functional groups. The goal is to interview experts from the following groups: managers, project leaders, technical project developers and process advisors/managers.

The experts from the industry are selected based on their experience in the industry, focusing on the utility building industry and different approaches, which are more from the design and development, construction, and management side. These three approaches are the focus in selecting the experts. This input, the approached experts, was recited by this study's direct advisors from the Royal BAM Group. Based on the contact information, email, or phone that is gathered, the experts are contacted for an interview.

The following actions will be conducted to ensure that the interviewees understand the questions. First, by the specific terms of the interview, a definition is given to elaborate and take this as a pre-assumption for answering the questions. This makes it easier to understand the direction of the questions. Furthermore, during the interview, the questions will be elaborated on and explained, making it easier to answer the questions in the right direction. During the interview is asked if the interviewee understands questions.

3.3.1. Set up interviews and reasoning

Then, in the performed structure of Rowley (2012), the questions are discussed and explained why these questions are needed. The interview guide with questions is added in Appendix 1, with an English and Dutch version. Most of the interviews will be conducted in Dutch. Therefore, the questions are translated. Furthermore, for extra in-depth information, one can consult the transcript of the interviews in Appendix 2.

Three sections divide the questions, and the first part aims the introduction of standardisation, which is the core of this research. The second part focuses on the design and product part, and in the last section, the process is the central theme.

General questions

1. *What means standardisation for your function?*
2. *How are you involved in standardisation?*
3. *Why should the construction industry implement standardisation?*
   3.1. *What are barriers to the implementation of standardisation?*
   3.2. *How could these barriers be solved?*
   3.3. *How can standardisation be stimulated in the utility building industry?*
   3.4. *What are potential challenges to the implementation of standardisation?*
4. *How are parametric, modular design, and standardisation related to each other?*

The questions above are asked to know how the concerning interviewee is involved with standardisation. That is relevant because each interviewed function type has a different approach to standardisation. Furthermore, the questions focus on why, how, and what about standardisation in the construction industry. Here, the literature review structure is followed and asked about their perspective of standardisation, the barriers to standardisation, and how to solve the barriers and challenges.

Design – Product questions

5. *How do you see the interrelation between flexibility and similarity?*
6. *In which form would the client react positively to standardisation?*
7. *Which utility building elements should and can be standardized?*
8. *Which design parameters are relevant for the design of standardized utility elements?*

These questions are more or less focused on the product, which involves the design of elements in the industry. The question that focuses on flexibility and similarity is requested to see how the interviewee interprets the role of the design concerning standardisation. Because that is one of the main challenges to overcome, this question is conducted. Then other significant challenges are the client's advisors and the client itself that influence how standardisation is applied. Tried is to identify how this can be approached and can be tackled. Furthermore, more design-related questions are to identify new approaches to defining which elements should be standardized. And then also how to define these elements based on parameters.

Process questions

9. *What should a standardized design process for utility building elements look like?*
10. *Which 'process attributes' are relevant in the design process?*

These questions are asked to identify how the expert approaches these questions, which can help this study because new approaches can help identify other solutions and insights. These are maybe the most important ones because it is a complex problem that is tried to be solved, and therefore creative solutions are needed.

11. *Do you have other related knowledge or connections that can help this study towards standardisation? What did you think about this interview?*

Then the last question is always asked for feedback, and if the interviewee has more ideas about this research and if they have connections in their network that can help with this study towards standardisation.

In general, most questions are asked to identify other approaches that can help solve this research. Other approaches can help to see new perspectives for solving the questions of this research. The comparison and combination of theory and practice enable different insights that will help create a standard design process and design parameters that fit theory and the current practice.

1.1.1. Definitions used in the interviews

The definitions used during the interviews are extracted from the glossary list of this study. A short and practical description is created in all the definitions that fits the questions.

Standardisation: no definition for this term because it is the first question of what standardisation means from the interviewee's perspective.

Barriers: an aspect that has a negative influence and prevents the implementation of standardisation.

Potential challenges: These aspects could be seen as an action that should be tackled to promote the performance of standardisation.

Modular design: designing with the focus on prefabricating building components/elements/modules based on easy assembly and disassembly.

Parametric design: the design of a project based on a fixed amount of design parameters, therefore enabling generative design based on the input of these parameters.

Elements: a building element contains different products and components, which have multiple functions and are relatively easy to prefabricate. A module can consist of more elements.

Design parameters: aspects that indicate the different sizes/dimensions/proportions/appearance of an element and also consist of products and components.

Process attributes are tasks or influences that occur and perform during processes.

3.4. Interviewees

The following experts, Table 1, are interviewed for this study towards standardisation. Tried is to interview experts from the four different functions group: project developers, project leaders, project managers, and directors. Therefore, these experts with these functions have different approaches to this research problem and are interviewed. However, many directors were interviewed, and there were many experts interviewed from the Royal BAM Group. That can influence the results of these interviews.

Furthermore, a subcontractor is interviewed to identify how this stakeholder is involved in new construction projects' design and engineering processes. Moreover, there is made a distinction in the contribution of the expert during the project life cycle process and in which type of construction the expert is active. Table 7 gives an overview of the type of experts that is interviewed. These distinctions are not used during the analyses of the interviews because, except for the function title, it has no specific influences.

Case	Function	Company	Process phase contribution	Type construction
Case 1	Process manager	BAM A&E	Engineering & Construction	Management development processes
Case 2	Project developer	BAM A&E	VO to Construction	Utility building
Case 3	Director	Groot & Vissers	Supplier construction	Facade utility buildings
Case 4	Director	BAM B&T	Construction	Utility building
Case 5	Director	BAM Wonen	Construction	Residential
Case 6	Director	BAM B&T	Construction	Utility building
Case 7	Project developer	BAM SP	VO to Construction	Utility building
Case 8	Director	BAM B&T	Construction	Utility building
Case 9	Process manager	ABC Nova	Initiative to Construction	Management of projects
Case 10	Project director	BAM B&T	Construction	Utility building
Case 11	Process manager	BRINK	Initiative to Construction	Management of projects
Case 12	Projectdeveloper	BAM B&T	Engineering & Construction	Utility building components
Case 13	Project director	BAM B&T	Construction	Utility building

Table 7 - Overview of experts interviewed

3.5. Interview analysis

The interviews are analysed by thematic analysis by the software of ATLAS.ti according to a specific coding structure that is based on the literature review. These aspects are elaborated further in the following sections.

3.5.1. Type of analysis

For the analysis of the interviews, thematic analysis is executed as a method. This analysis method enables to do qualitative research by textual analysis. Furthermore, this method can be performed to identify and distinguish the questions on different topics. These interviews aim to study the practical insights of standardisation in construction, which can generate new approaches to implementing standardisation. Furthermore, with the performance of thematic analysis, it is possible to reflect the results of the interviews with the literature review. The interviews are based on the gained insights from the literature review.

Therefore, the following structure of Jodi (1994) is used to perform a thematic analysis.

1. Familiarization

The first step is to conduct all the interviews and organize these. From this first part of transcribing the data, the first familiarization occurs.

2. Coding process, highlighting

Then, based on the questions asked, the first phase of the coding process is conducted. Per question, the answers are coded. The coding highlights essential words, sentences or parts of sentences, which structures the first information per question.

3. Themes are generated

Based on the generated codes, general themes are created that combine these codes. The codes are combined in these overall code groups, as these are named in ATLAS.ti. These groups of codes are primarily indicated to the following structure that is extracted from the interviews:

1. Organisation related codes
2. Stakeholders related codes
3. Product-related codes
4. Process related codes
5. Financial related codes

4. Review themes

Then afterwards, it is crucial, according to Jodi (1994), to argue and review the themes. Then, the themes and results of the interviews are related to the literature review.

This method helps to approach and analyse the interviews in a structured manner. Furthermore, by indicating themes between codes, a more conceptual view can be generated from the results. This conceptual view, i.e. framework, indicates the main objectives and concepts necessary for standardisation in the utility building industry.

3.5.2. ATLAS.ti

For coding and analysing the results from the interviews, the software of ATLAS.ti 22 is used. This software enables us to work on a structured method to analyse the text documentation of the interviews. The software was available from the Eindhoven University of Technology from the Building Faculty. Furthermore, the software is easy to handle and can have good results in diagrams. These will help in doing thorough analyses of the interviews. Therefore, this software was chosen and used for this research.

3.5.3. Example of coding

The following example is elaborated to indicate how the coding process is applied. First, the codes already generated for this question are used to answer the question. The codes 'increase safety', 'less engineering', and 'fewer craftsmen needed' are identified, while 'sustainability' was not defined. After the coding process, all the interviews are analysed again to indicate the newly identified codes. These were applied if applicable.

3. Waarom zou de bouw moeten standaardiseren?

"Heeft te maken met capaciteit, haalbaarheid maken van project, schaalvoordeel, werken op de hoogte en dus veiligheid. Minder uren op hoogte bezig. Ook de energiecrisis.
Wat je ook ziet is dat er veel woontorens worden gebouwd, maar dat het elke keer helemaal opnieuw wordt ge engineerd. Waarom zou je niet dat concept vaker willen toepassen? "

Coding: increase safety

Coding: fewer craftsmen needed

Coding: less engineering

Coding: sustainability

3.5.4. Coding structure

The coding structure, given in Figure 16, used for coding the interview results is based on the question structure that is answered. The goal is to indicate the essential concepts per question and review if these concepts occur more often among different interviewees. Therefore, per question, codes are generated based on the results of the interviews. After the coding of the process, the codes are structured into new themes within the question. This process has led to the following total coding system where different general code themes are generated and then the specific codes per question.

Name	Grounded
1 Meaning	47
2 Barriers	41
2.1 Barrier Organization	15
contracts	3
dependent of markt	5
general goal	1
inexperience with standardization	1
solution irt demand	6
2.2 Barrier Stakeholders	17
2.3 Barrier Financial	1
2.4 Barrier Product	7
2.5 Barrier Process	2
3 Solve Barriers	25
4 Stimulation of standardization	21
5 Potential challenges	20
7 Involve advisors/client	17
8 Utility building elements	28
9 Relevant design parameters	14
Indepedent codes	119

Figure 16 - Coding structure

3.6. Interview results

This section describes and interprets the results of the interviews. That analysis occurred based on the coding results, which the study translated into graphs. These graphs indicate how often the codes occur, per question, a graph show these results.

Perspective of standardisation

This question elaborates on the current view and definition of standardisation in the utility building industry. Figure 17 shows the results. According to the industry, the following three main approaches are indicated during the analysis of the meaning of standardisation. First of all, standardisation implies reducing variables, which indicates the simplification of used variables or parameters in the design of a product or the development of a process. Then, with this reduction of variables comes the performance of a standard construct. This construct could be a standard process or standard element. That implies the same structure, i.e., approach. It generates control over the construct and increases the efficiency of material use or assembly processes. A third aspect, standardisation, suggests another organisation is needed that focuses on developing standard elements, incorporating feedback, and actively selling the product or process.

So, standardisation is defined by three main approaches according to the industry: reducing variables, the performance of a standard process or product, and another organisation around that construct.

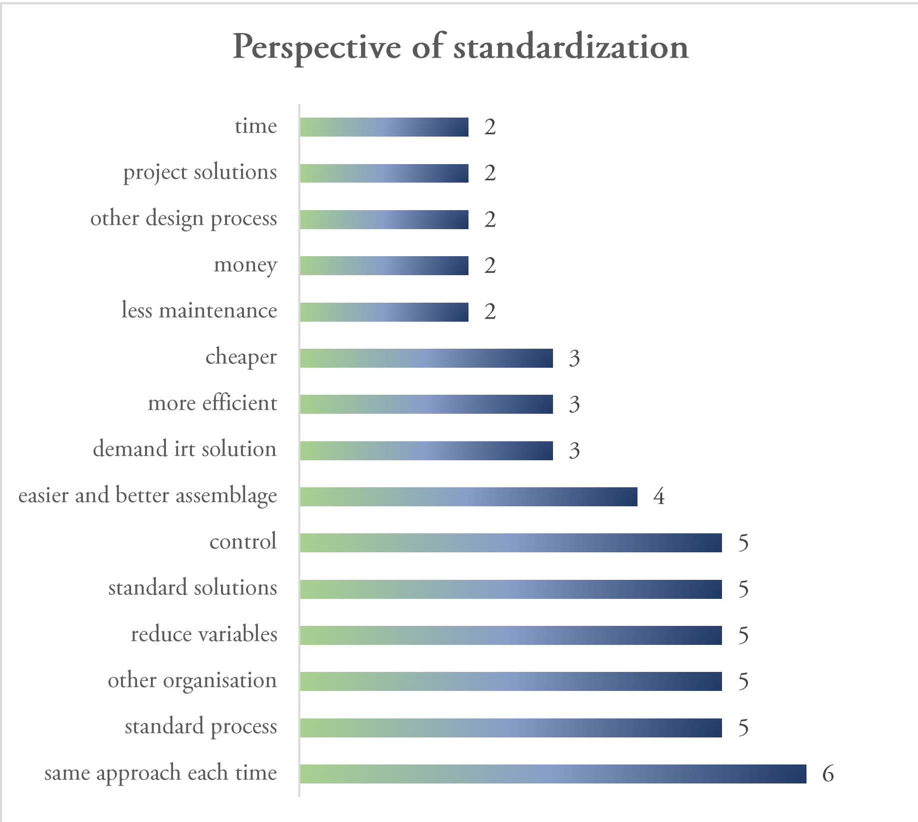

Figure 17 - Perspective of standardisation

Benefits of standardisation

This paragraph asks about the benefits of standardisation for the utility building industry. According to the interviews, the following benefits, overviewed in Figure 18, are the most important. These are positive consequences of standardisation in the utility building industry: the decrease of failures, which could be supposed as construction errors or design errors, which will be less with standard elements. Furthermore, the financial results will be better, which is the general thought as a positive consequence of standardisation. Moreover, the final product will have higher quality than the current final products. Then, the solution will generate more efficient reasoning from the process and product approach.

The most important benefits are more focused on efficiency, which implies that this is an essential aspect of the industry. At the same time, the more sustainable benefits are less important.

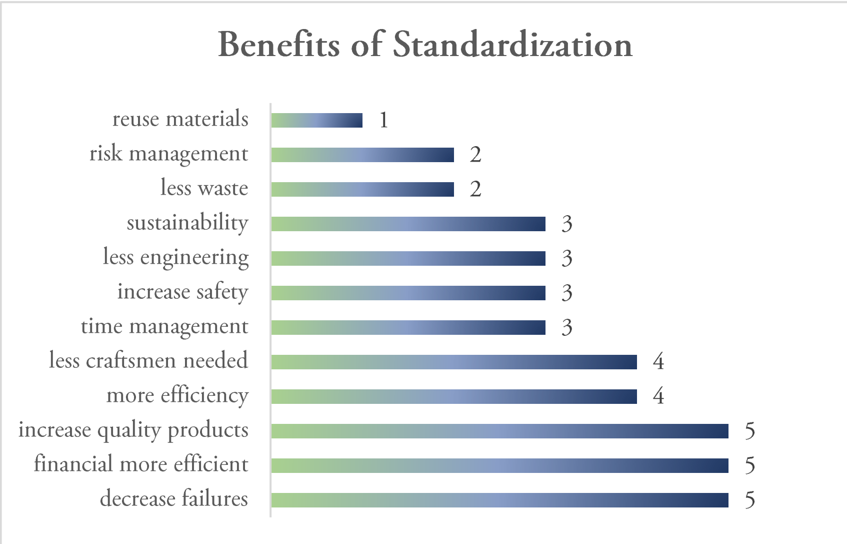

Figure 18 - Benefits of standardisation

Barriers of standardisation

Within this section, the focus is on the barriers that impact the implementation of standardisation. The first main barrier to standardisation is the culture between the different stakeholders of the design process. This culture indicates the mindset of the stakeholders that focuses on creating and building each project new solutions, which is currently more traditional focused. The other main barrier implies that the solution should meet the client's demand. Here, the experts suppose that the standard solutions should fit in the context of the already designed building of the architect. That has many implications. The barrier indirectly relates to another barrier that describes the esthetical barrier of standardisation. With standardisation, the esthetical freedom of the architect will be refocused.

Furthermore, Figure 19 shows that the main barriers arise from organisational and stakeholder approaches, besides the three significant barriers. That means that the solutions to these barriers should be in the same direction.

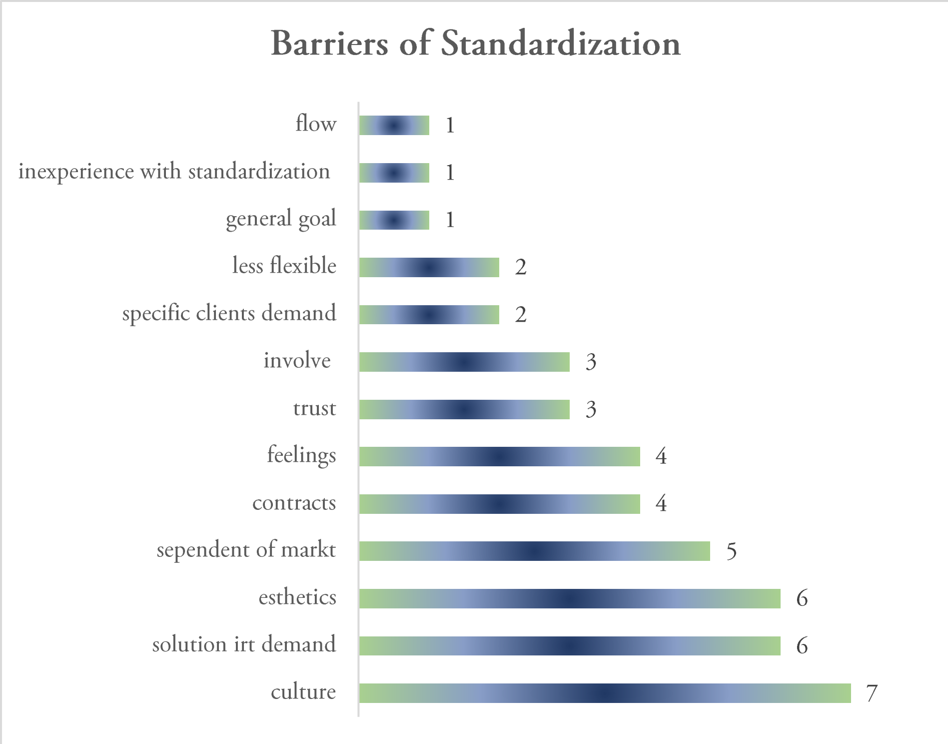

Figure 19 - Barriers of standardisation

How can these barriers be solved?

The main barriers, given in Figure 20, on the stakeholder and organisational level can be solved by showing what standardisation implies. In this case, real-life standard solutions should the contractor demonstrate to the client and all stakeholders. The consequences of that standard product are significant, financial efficiency, quality of the products, and an increase in safety. Another solution can be to define the same goal

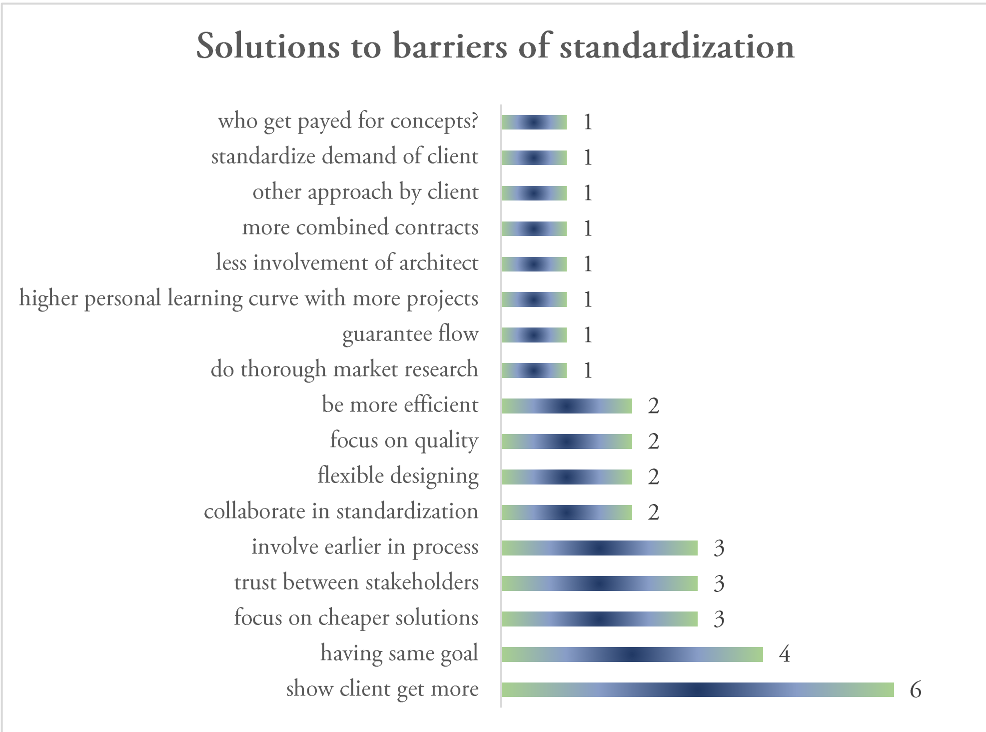

Figure 20 - Solutions of barriers from standardisation

within the whole company to get the employees involved. However, it is essential to have a clear and viable approach. The other approach to solving the barriers can the contractor find around standardisation within the organisation. Reorganisation is an integral part of solving barriers. With this reorganisation, the management of standard concepts is a significant challenge.

Furthermore, in Table 8, the barriers and the solutions extracted from the interviews are applied. Some solutions are not used because there was no direct link to a barrier, and some barriers do not seem to have a related solution from the interviews. This Table is the first to thorough implementation of standardisation.

Barriers Interviews	Solution
Culture	Trust between stakeholders Collaborate in standardisation
Solution i.r.t. demand	Show client get more Flexible designing
Aesthetics	Flexible designing
Dependent of market	
Contracts	Apply more combined contracts
Feelings	Having the same goal
Trust	Show client get more Having the same goal Transparency
Involve	Collaborate in standardisation Involve early in the process
Specific clients demand	Who gets paid for concepts?
Less flexible	Show client get more
General goal	Involve early in the process Having the same goal
Inexperience with standardisation	Collaborate in standardisation
Flow	
Production process	Guarantee flow

Table 8 – Barriers and solutions

How can standardisation be stimulated in the utility building industry?

The stimulation of standardisation, an overview given in Figure 21, in the utility building industry can the contractor reach by the following aspects. The significant results relate to the solutions for more standardisation, involving stakeholders in the standardisation and demonstrating solutions to all these stakeholders. Furthermore, focusing on efficiency and modularity standardisation will be stimulated, as stated in the interviews.

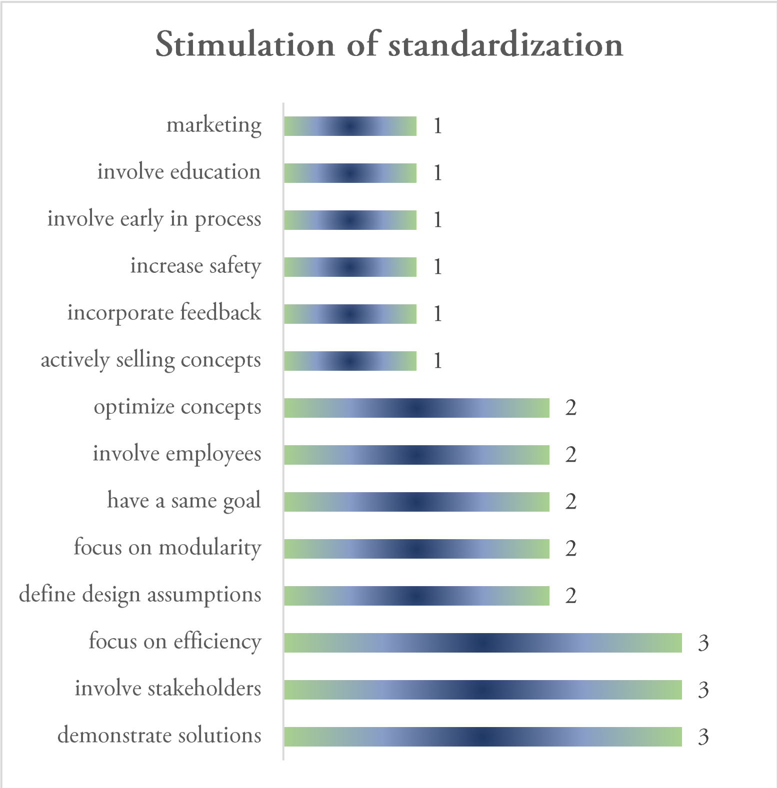

Figure 21 - Stimulation of standardisation

What are potential challenges to the implementation of standardisation?

The following aspects in Figure 22 are the main challenges of implementing standardisation in the utility building industry. The main challenge is the mindset of all stakeholders in the project life cycle. Furthermore, another organisation is needed to apply standardisation with an efficient method. The current contractors are too focused on projects and not on standard concepts, which should be changed when the focus will be on standardizing elements for the utility building industry.

Figure 22 - Challenges of the implementation of standardisation

How can the client, and its advisors, be positively involved relating to standardisation?
The following results, given in Figure 23, are aspects to enhance the involvement of the client and advisors in more standardisation. Therefore, according to the experts from the utility building industry, a significant factor is to demonstrate that the solution is cheaper and has proven quality. The contractor will convince a client that a cheaper solution with more quality and specific functionality can be applied. These requirements and assumptions are essential for developing the standardized design process for the elements that the contractor will design.

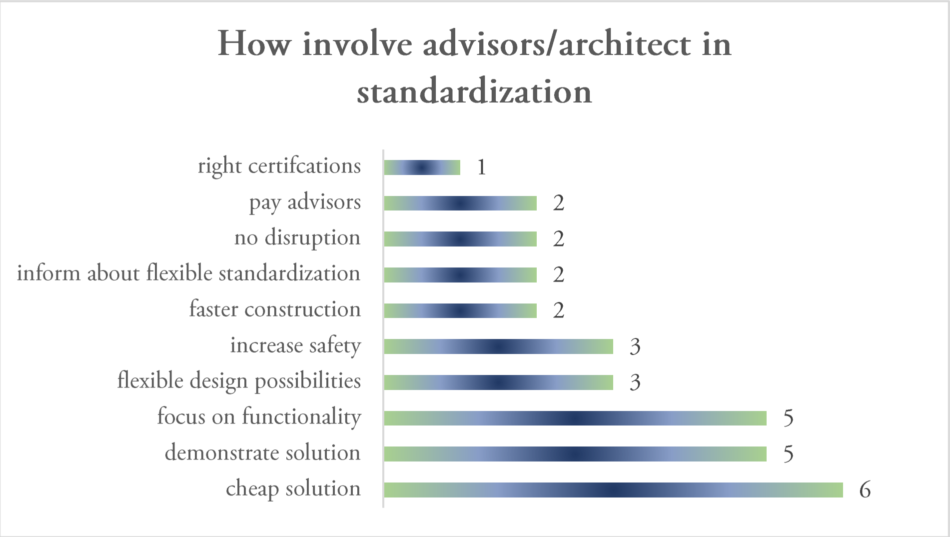

Figure 23 - How to involve the clients and architects in standardisation

Which utility building elements would you standardize?
According to the experts, the following aspects given in Figure 24 can the industry standardise. The experts' approach differs in defining specific elements that should be standardized. Some show examples of specific elements like installations and toilet groups. In contrast, other experts approach this question more from the designing process. They indicate that dimensions of the building, i.e., elements, should be standardized or more focused on interfaces between these elements. These other approaches give new perspectives on the structure of the elements, solutions, or directions that can be standardized. This perspective involves specific elements of installations, building physics, construction, and structural.

Furthermore, from regulations, information on processes, general dimensions of building types, and materials used in solutions. More levels define solutions that can be standardized. These levels, or approaches, should be worked out to make this more specific.

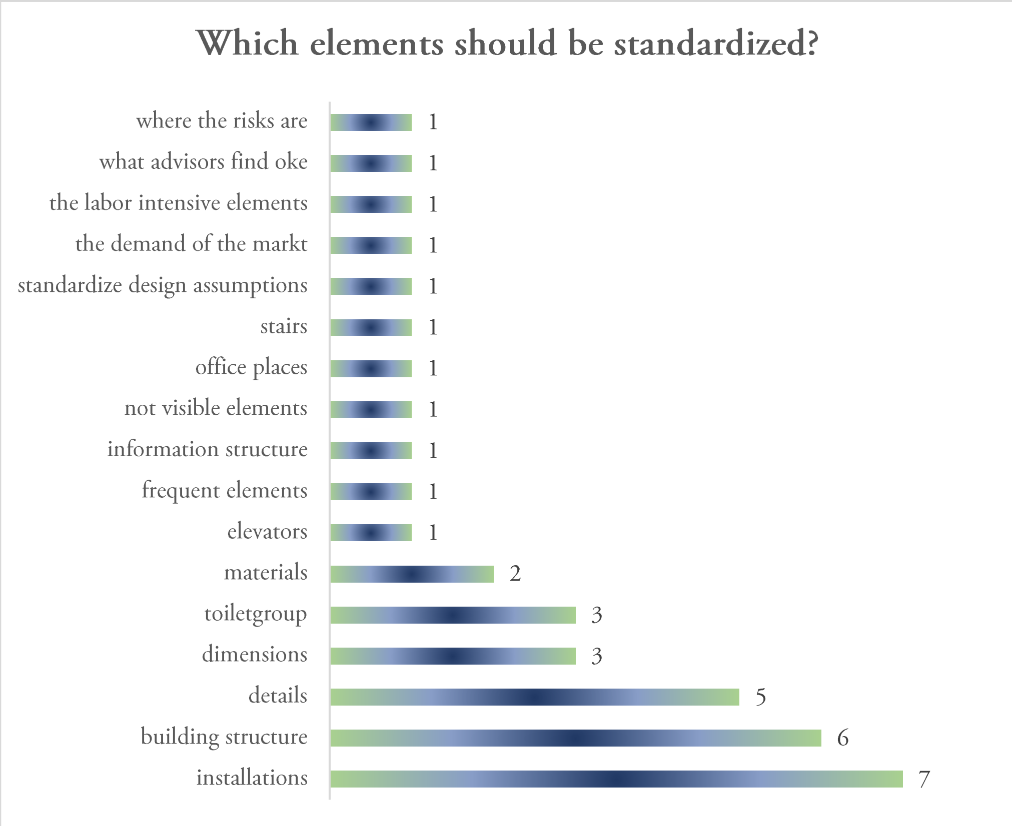

Figure 24 - Which elements could be standardized

Which design parameters are relevant for the design process of utility building elements?

The results of this question are in line as the question focused on the elements. That implies that the answers are not all specific design parameters, according to Figure 25. Some answers are more general and indicate a more effective conceptual approach to defining design parameters than clear answers like the height or dimensions of solutions.

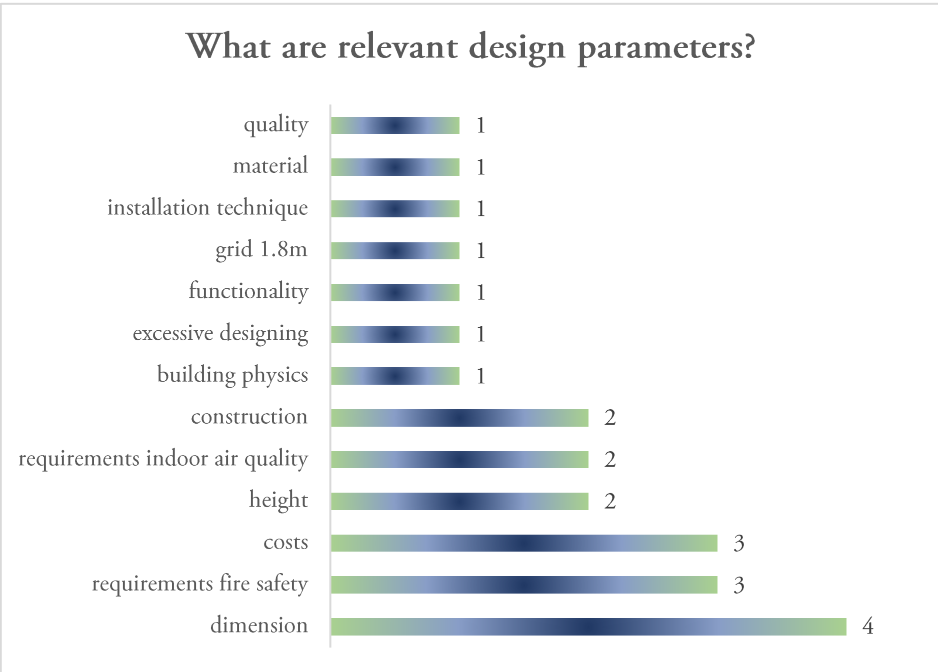

Figure 25 - What are relevant design parameters

3.6.1. Analysis results interviews

Thus, all the questions are analysed one by one. This section conducts a primary analysis of all questions. Figure 26 combines the following aspects, which gives an overview of the most critical issues to tackle to enable and enhance standardisation in the industry. The Figure will be necessary during the implementation phase when the contractor should solve all these issues, solutions, and actions. The three main aspects, which this study extracts from the interviews, are elaborated on below.

1. Mindset/culture

   This standardisation component is indicated in most questions and indicates barriers, challenges, and stimulation aspects. This mindset and culture of the current employees, stakeholders, and other involved organisations are focused on traditional construction and have their limitations in quickly implementing standardisation. Changing the current practices from project-specific to more standardisation is probably the hardest challenge to tackle because it are the people that need to change, which a hard and social task. This challenge should be studied more thoroughly and seriously taken into account.

2. Organisation

   Another aspect that is part of the standardisation and indicated in answers to many questions is the organisation around standardisation. With standardisation, another organisation is needed, concluded in many answers. This new organisation should focus on elements, its design, its management, the marketing around the elements, and many other aspects. The current industry is a project organisation, focusing on constructing as many projects as possible. A concept organisation is needed with standard elements with the specific parts described above.

3. Demonstrate solutions

   An essential aspect is to demonstrate solutions whereby the client and advisors are essential to consider. By demonstrating elements or solutions, the stakeholders and employees can be positively involved. It is essential to consider the following aspects with demonstrating solutions: that it is financially more efficient, increased quality, increased safety, and design freedom with the solutions.

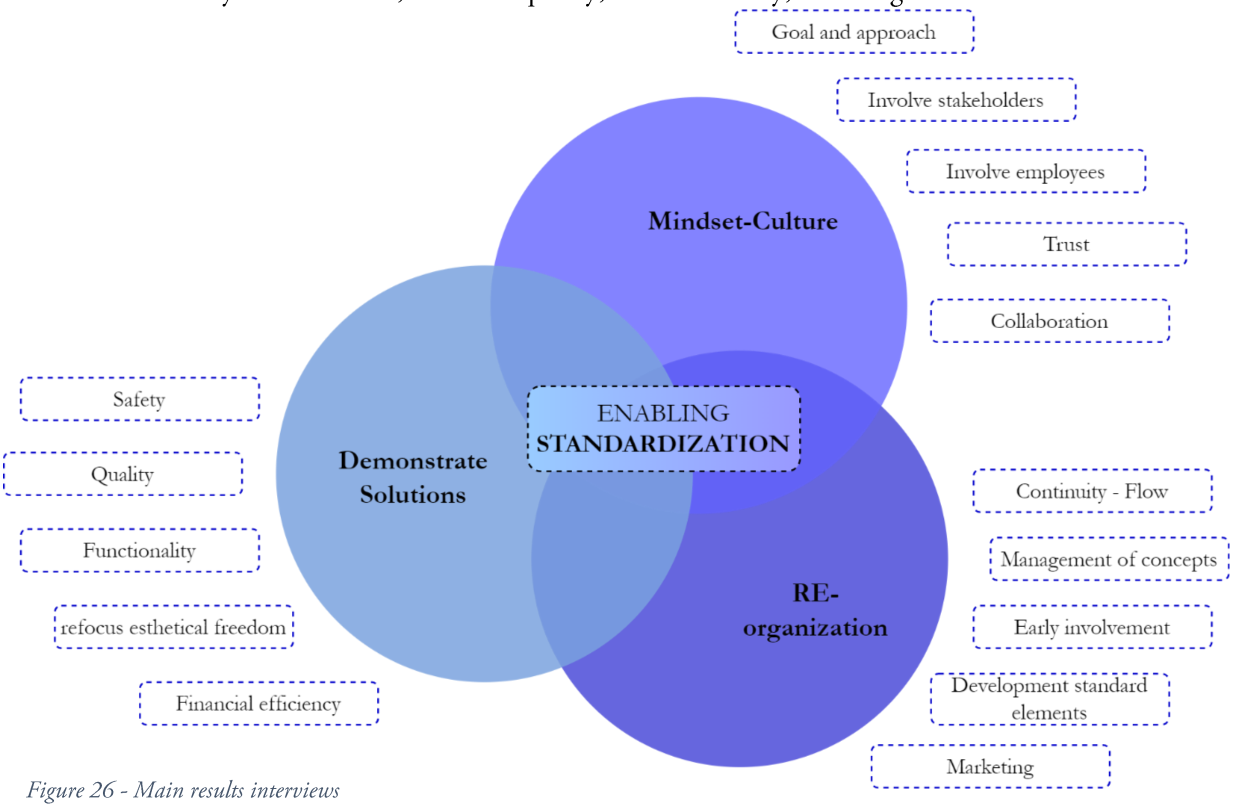

Figure 26 - Main results interviews

The three identified challenges are essential to tackle for performing and implementing standardisation. It are fundamental problems the utility building industry is facing because standardisation is the opposite of project specific designing. Standardisation challenges the current practices of the industry and are therefore hard to tackle, the industry designs, develops, constructs project specific for centuries, which negatively influences the need to change to something that is not proven. This study develops answers for the implementation of standardisation, chapter 5.9, and identifies which challenges are essential to tackle. Furthermore, the study proposes a standard design process as guiding for the design and development of standard, parametric and modular elements. After this chapter, the study develops this design process and therefore tackles the first significant challenge: demonstrating solutions.

3.7. Comparison literature review and interviews

This comparison evaluates the literature study on the utility building contracting situation in the Netherlands. Three comparisons indicate the differences between the scientific and practical approaches by evaluating barriers, challenges, and benefits. These comparisons are conducted in synthesis matrixes that the study uses to assess the results. The numbers in the tables, indicated by the column count, imply how often the concepts are shown during the 13 interviews and therefore indicate how vital an aspect is.

3.7.1. Comparison barriers

Table 9 compares the barriers to the literature review and the interviews. Seen is that the barriers of the interviews cannot be translated directly to the defined barriers according to the literature review. Because the interviews have a more practical approach and the literature review a more scientific conceptual approach, some barriers identified during the interviews indicate one barrier of the literature review. Since barriers from the interviews are more specific interpreted, multiple can be compared and assessed to more conceptual barriers from the literature review. Thus, the dependence on the market, involvement, and trust are related to the conceptual barrier that describes the failure to involve suppliers and manufacturers early. According to the literature review and interviews, this comparison indicates a value of 10 and is the most significant barrier.

In conclusion, the organisation and stakeholder barriers relate the most to the barriers of the literature review and are thereby the most significant barriers. These barriers imply why the utility building industry cannot implement standardisation.

Aspects literature review	Count	Aspects interviews
Failure to involve manufacturers and suppliers early	5 2 3	Organisation: dependent on the market Stakeholders: involve Stakeholders: trust
Failure to apply S&P within an overall business or project strategy	6	Organisation: solution i.r.t. demand
Failure to stimulate innovation	6	Stakeholders: culture
Failure to get full project team commitment	1 3 1	Organisation: inexperience Stakeholders: feelings Organisation: general goal
Failure to make key decisions at the optimum time	3	Organisation: contracts
Clients' views on standardisation	2	Stakeholders: specific clients demand
Failure to change process from construction to manufacturing	1	Process: flow
Failure to measure benefits		
Failure to consider all relevant costs		

Table 9 - Comparison literature review - interviews of barriers and challenges

3.7.2. Comparison challenges

This same process compares the challenges between literature study and interviews. The challenges from the interviews have a specific character. In contrast, the literature review challenges have a more conceptual character, which is extracted from Table 10. Furthermore, the most complex tasks to overcome are the mindset and the implementation of standardisation because the study indicates these two challenges the most. Then, some aspects are identified as barriers, while it can either be a challenge. The contracts are defined as a barrier in the interviews, while the literature indicates it as a challenge. Consequently, this implies that there could be an overlap in the definitions of barriers and challenges.

Then, this study indicates no relations between literature study and interviews for some challenges. These challenges are planning, flexibility and contracts. That implies that both studies do not directly indicate these challenges and therefore have less value as a challenge instead of challenges that both studies identify.

Aspects literature review	Count	Aspects interviews
Implementation	5	other organisation
	2	goal and approach
Mindset clients	6	mindset
Mindset designers	1	employees
Collaboration	2	optimize solutions
Quantification	1	flow
Planning		
Flexibility		
Contracts		

Table 10 - Comparison literature review - interviews of barriers and challenges

3.7.3. Comparison benefits

First of all, important to state is that the benefits indicated in the interviews are not divided into a process or product benefits but applied in both directions because these benefits do not explicitly represent a specific direction. Table 11 gives this overview. It defines per benefit of the interview to which benefit of the literature review it relates or not. Some benefits of the interviews are applied two times, at the process and product benefits of the literature review.

Aspects literature review	Count	Aspects interviews
Process Benefits		
Improved quality control	5	increased quality products
Better able to cope with congested sites	3	fewer craftsmen needed
Minimised disruption	3	time management
Increased productivity through familiarisation	2	less engineering
More predictable on-site activities	2	risk management
Less waste, noise, dust, e.t.c.	2	less waste
Statistical reduction in H&S and environmental hazards	2	increase safety
Rationalised interfaces		

Product Benefits		
Greater certainty of the completion date	3	time management
Minimised overall project time	4	more efficiency
More predictable lead-in times	5	increased quality products
Increased productivity through familiarisation	2	less engineering
Reduction of waste	2	less waste
Use of the same components on follow-on projects	1	reuse materials
Available replacement parts		
Tried and tested track record		
Predictable quality & performance		
Off-site inspection		

Table 11 - Comparison of literature review - interviews benefits standardisation

This comparison sees an overlap between the benefits of the interviews and the literature review. This comparison implies that the benefits are mainly in line with each other from the scientific and practical approaches. The benefits from the literature review are defined very precisely, while the benefits of the interviews are more conceptual than those from the review. Therefore, this section sees an overlap between benefits that indirectly imply the same. For example, the benefits of time management and more efficiency extracted from the interviews have three benefits defined in the literature study: minimised overall project time, more predictable project time and more predictable lead-in times. This relation is based on the more conceptual definition of the benefit of more efficiency and the time efficiency implied by the literature review's benefits.

Two benefits extracted from the interviews do not overlap with the benefits of the literature review: the benefits of decreasing failures and the more financially efficient results with the application of standardisation. While the interviews indicate these benefits as very important, here is seen that the literature review misses some benefits from the more practical approach.

In general, the comparison between the literature review and the interviews with the experts is that most results are not easy to compare. Because the interviews are conducted with experts from the industry, the results are too focused on the current practical status of standardisation in the utility building industry. While the scientific approach, the literature review, is more conceptual and consists of more general answers. However, the results of the interviews are translated to a more abstract level and are better than the literature review. By defining more general overlapping themes of the answers of the interviews, it achieves a conceptual level. By indicating how often an aspect is coded during an interview can be concluded how significant a barrier, challenge, or benefit is.

3.8. Conclusion

This section elaborates on the conclusion of this chapter. Furthermore, it discusses some boundaries of the interviews and comparisons to identify how to interpret the results.

The interviews indicate the current situation of standardisation in the utility building industry. This situation of standardisation and how it can enhance the industry are summarized and coded into graphs. Situating that standardisation is still not often applied in the utility building industry, these experts see the advantages of applying the concept definitively. These new perspectives generate a structure that describes all the industry's approaches to standardisation that should increase. That consists of mindset, i.e., culture, a re-organisation, and the demonstrating solutions. Figure 26 includes all the necessary conditions to stimulate and enhance standardisation based on the three aspects of standardisation.

The comparison between the literature review and the interviews is conducted in synthesis matrixes, which generates a structure that enables a good overview. The comparison bases the content on the studies' identified barriers, benefits and challenges. In conclusion, a difference in barriers and challenges between the literature study and the current situation is identified. This difference implies the more conceptual approach of the literature and the more practical approach of the industry experts. However, there are also more overlapping sections in this comparison. These overlapping sections focus on the stakeholders and the organisation around standardisation. Where the literature review indicates more conceptual barriers and challenges, the industry experts suggest more specific practical barriers and challenges. While comparing the benefits demonstrated by the interviews, a more abstract approach is recognized, and conversely, the literature review benefits are a more specific approach. So, a conclusion is that the experts define the benefits more conceptual, maybe because they do not indicate concrete benefits. They imply that the industry does not see specifically the beneficial results of standardisation, which is also a barrier shown in the literature review.

The interviews were semi-structured; this influenced the results of the strict comparison with the literature review. Some interviews were too unstructured, making it hard to ask all the questions. That could influence the results by not having answered all the questions. Furthermore, this study interviewed many experts of the Royal BAM Group, which can impact the results. In the way that other perspectives are missed or not indicated. Therefore, this is a limitation of these interviews. However, the experts from BAM are from different disciplines and companies, which implies that the study incorporated more perspectives and other approaches.

4. Model: Development Standardized Design Process

This chapter develops the process map of the standard design process of utility building elements.

4.1 Process Map indication

This section focuses on developing this process map based on the Business Process Map Notation (BPMN). Therefore, first, this development process's goals and assumptions are elaborated. Then, it is reasoned and discussed which part of the overall construction process is standardised and how this developed process should fit into the whole construction process. Lastly, the section elaborates on the BPMN and the approach to designing the BPMN.

4.1.1. What is standardised?

This study towards standardisation in the utility building industry incorporates two directions of standardisation: process direction and product direction.

Process:
This chapter develops the design process of utility building elements to standard. That implies that the proposed design process becomes the norm and rule to perform when a contractor designs a utility building element.

Product:
The product, the utility building element, is developed by performing the standardised design process. That results in a standard, modular and parametric designed element. Standard implies that the component consists of a fixed number of parts and a fixed number of design decisions that the designer can make. Thus, the parts used in the elements are simultaneously but can differ in size, length and other parameters.

4.1.2. Goal and assumptions process map

This process must be standard because that generates value in the form of productivity, efficiency, safety, and quality, according to the literature study and conducted interviews. The first steps of standardising elements within the utility building industry can start with this proposed process.

4.1.3. What part of the process is standardised?

This part elaborates on the proposed standardised design process of utility building elements. It is important to scope the approach that this study suggests. Otherwise, this developing process is not structured enough and has no direction. Figure 27 indicates how the proposed method is part of the project life cycle.

Start: The start of the design process of standardised elements is the initial moment, which includes the decision to start with the design of an element for the utility building industry.

End: The end indicates when the design team developed a standard element to the definitive and technical level. After the design process to the technical level, the contractor can apply the developed element in a project design, and it is ready for production.

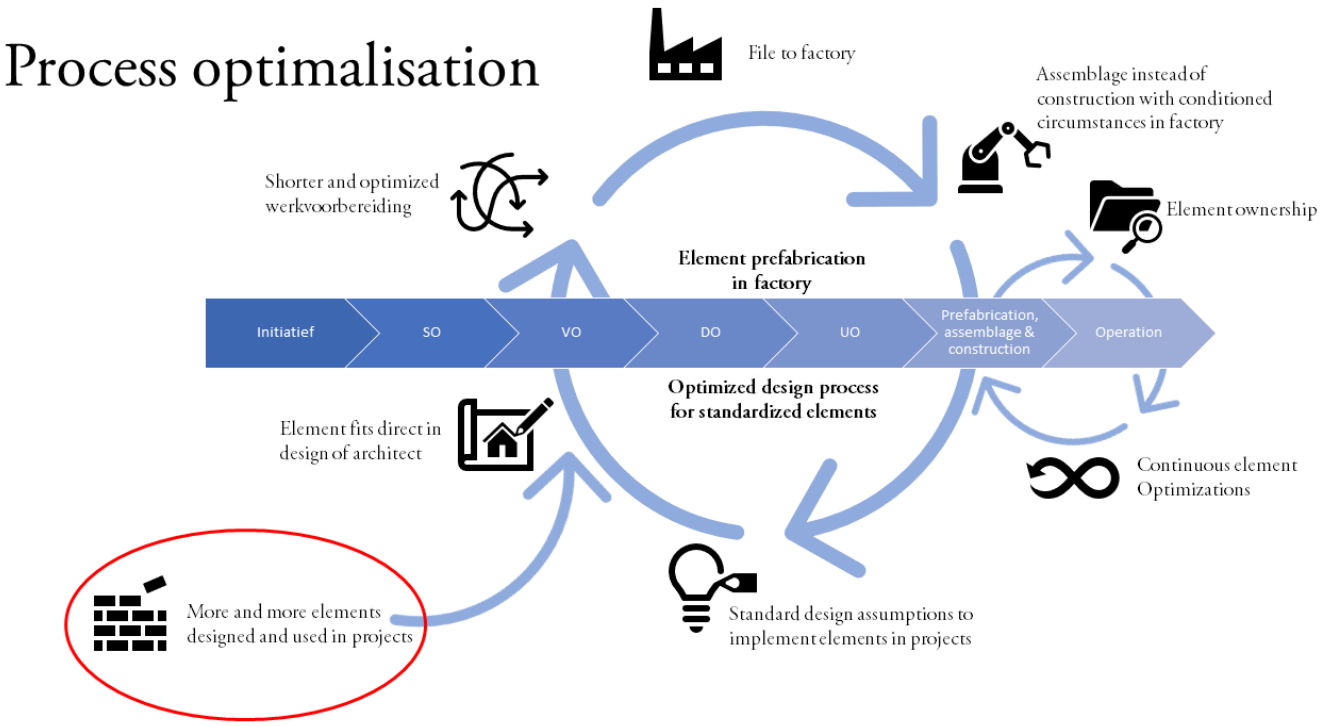

Figure 27 - Process optimalisation project life cycle

4.1.4. Who will be the user of the process?

Contractors that focus on industrialisation and want to meet future demand can apply this proposed design process. It is essential to note that this study proposes this design process for larger contractors in the Netherlands that can design and develop these elements.

4.1.5. What will be the value for the process user?

The value of the standardised design process for the developer of these standard elements focuses on the structure that this process offers to design components. This proposed process fits the current construction industry and can easily be applied. Furthermore, the method provides a learning procedure for creating multiple elements due to the repetitive character of the process. Moreover, this process addresses significant barriers and challenges by tackling these and focusing on the enablers of standardisation. Therefore, this process fits the company's standardisation and industrialisation goals.

4.1.6. Definition of elements

Defining what the contractor can design with this proposed process is vital, and this paragraph elaborates on that. This definition of elements is complex because there is no specific definition applicable to all elements in the construction industry and the utility building industry. After all, elements have dimensions whereby different construction disciplines are applied, and it has multiple interfaces with other building parts. This elaboration becomes evident in the following examples, which this study uses as references. The description on the next page indicates illustrations from different disciplines to specify the definition of elements. The analysis extracts these examples from the semi-structured interviews conducted for this research. The main objectives to standardise, according to the interviews, are installations, building structure, details and toilet groups. The following section defines these building components as elements.

Installation: Distribution rack - Distributiebaan

Figure 28 - Multiple elements in a project (source see 1)

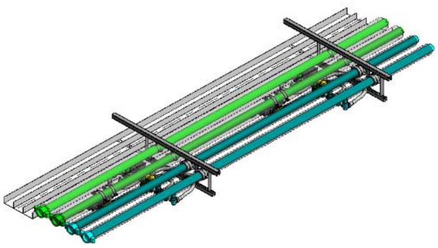

Figure 4 - Overview example element

This element is an installation that transports warm and cold water to all building sections. The component uses a metal framework as the primary technological application so that the contractor can apply the element in various projects. Furthermore, this element consists of multiple functions, a significant characteristic of components in general. These functions are primarily the transportation of warm and cold water. Moreover, it has numerous interfaces with other building parts. Additionally, this element is applied in many utility buildings because many buildings need warm and cold water.

Besides, this example shows how the industry can apply standardisation. This component is designed to standard, with some variations, and can be applied very often, increasing quality, productivity, and financial feasibility.

Figure 28 gives an overview of multiple distribution racks ready to be assembled in a project. Figure 29 provides a more conceptual overview of the component.

Structural: structural concrete column

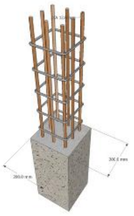

Figure 30 - Example concrete column

Figure 31 - Example concrete column

According to the proposed design process, this concrete column could be defined as a standard element. It could be seen as an element because it originates from one construction discipline: the building structure. Furthermore, it has multiple interfaces with other building parts and components. Moreover, this column should meet numerous functions during the operation phase. These functions are at least structural related and maybe esthetical or isolation related. At last, this element is applied very often in utility buildings, which generates value to standardise the component by creating a flow for production.

Figures 30 and 31 are examples of concrete columns.

Source Figure 30
https://3dwarehouse.sketchup.com/model/udeb7b4ac-b357-40a4-88f4-d364ab2ee979/Kolom-beton-bertulang-20x20cm?hl=nl
Source Figure 31
https://www.mdbeton.be/nl/md-beton-kolommen-in-gewapend-beton/

Technical: prefab façade element

Figure 32 - Example facade element

Figure 33 - Example facade element

Another example of an element is a façade part. This building component has multiple functions that it has to meet during operation, primarily esthetical, structural and water-resistant related. Furthermore, it has numerous interfaces with other building parts. Moreover, the element focuses more on the architectural discipline of a building.
Because this building part is applied very often and meets the above conditions, it meets the definition of an element, which the contractor can standardise. Figures 32 and 33 are examples of façade elements.

Source Figure 32
https://www.febe.be/nl/toepassingsgebieden/product/gevelpanelen-in-architectonisch-beton
Source Figure 33
https://www.stubeco.nl/4-uitvoeringsaspecten-bij-prefab-betonconstructies.html

This section discussed three examples as elements that the contractor could develop with the proposed design process. However, the analysis indicates no specific definition of elements in line with the interviews. Conversely, each example has multiple interfaces with other elements or building parts. Moreover, each sample focuses primarily on one discipline within the construction industry. These disciplines could be building physics, structural, esthetical, construction technics, and installations. Furthermore, each element has multiple functions that it has to meet.

It is essential to state that these examples and conclusions are focused on this research and are therefore hard to apply in other studies.

4.1.7. The chosen development Route

For the development of this design process, the study follows the coming method as a reference, according to Wix & Karlshoj (2010). The process discovery and data mining method is the route that is most in line for developing this design process. There is no initial process to start with according to this approach. The process is developed by iterations and discovering the method. The method consists of the following aspects:

1. Creating a process overview
2. Develop the process map
3. Develop the exchange requirements
4. Develop the functional parts
5. Define the business rules

By involving industry experts in the development of the process, more iterations with a practical approach can be made. Additionally, during the creation of the process, in the analysis phase, more iterations took place. These iterations enhanced the quality of the proposed process. Furthermore, the development approach has more in-depth steps and other important moments. This section does not elaborate on these explicitly.

4.2 Stakeholders involved

This paragraph elaborates on the involved stakeholders in the design process of an element. The reference case of the Hutter element indicates the involved stakeholders. Then, per stakeholder, this section discusses the drivers and barriers that arise with the design, development, assemblage and use of that element. It is essential to indicate the successes of a stakeholder and why it should participate in element standardisation. Furthermore, this process should eliminate potential barriers, and thus this section elaborates on these. Not all stakeholders participate in the design process of a standard element for the utility building industry. However, this section indicates these as necessary because of the influence the stakeholders have on the component.

End-user:

The end-user implies the person using the element in the final status, in the building itself. Furthermore, the end-user influences the design from a more functional approach. The element should be practical, usable, and esthetically appealing when visible during use.

Barriers: There are no main barriers to applying standard elements in this case. Because the Hutter element is not visible and has no specific functional added value to the end-user, the end-user does not have particular barriers to applying this element.

Drivers: With the application of the Hutter element, the end-user experience a more quality toilet and a lower possibility of failure during use. Drivers for the end-user are guaranteed quality during use and a lower chance of failure during operation.

The technical service team of the building

The service team of the building, where the element is applied, influences the practical and maintenance side of the component. This team is responsible for the operation of the whole building and the concerned elements. Therefore, the service team considers the change of failure during operation and how easy the team can solve a problem of the element during operation.

Barriers: the service team can indicate that the used Hutter element is new, and not often applied, whereby the quality during operation is not guaranteed. So, the contractor needs to increase the team's trust in new elements.

Drivers: the drivers for the service team are that the quality increases and thereby the failure during operation decreases, which is an advantage for the service team. Furthermore, it can be solved more effortlessly and efficiently when there is a failure because information about the element is known, and it is designed for better and easier maintenance.

Owner, financial investor

The financial investor, the building owner, influences the design of the whole building and is the client of the contractor. Therefore, the client is involved in the design process. The owner's goal is to have a healthy, quality, guaranteed facility that is esthetically appealing and within the financial requirements.

Barriers: a barrier for the owner could be that the element is too expensive and consequently cannot be applied.

Drivers: the drivers for the owner and the client of the building will be to achieve higher quality, lower costs, increase the project's safety during construction, faster construction, and thereby the project reaches higher feasibility. Furthermore, when the quality is guaranteed higher, the client can raise the rental costs of the building to their tenant.

The tenant

The tenant is the organisation that rents the building from the client, the owner. Thereby, the tenant is the end-user of a building project.

Barriers: the tenant wants to have a building that meets their requirements and is not too costly. The price-quality ratio is essential to guarantee a satisfied tenant. Therefore, barriers could be that the application of elements is too expensive, which results in higher rent costs. Moreover, if the quality of a component is not sufficient, it could be a barrier for the tenant.

Drivers: the drivers for the tenant are to achieve higher quality, have lower rental costs, faster construction to use the building earlier, and by standardisation, the design is more in line with the constraints of time and price as mentioned.

Advice team (architect, building physics advisor, structural engineer)

The advice team consists of the stakeholders that advise the client during the design phases. These are the architect that focuses on the whole building design. The installation advisor focuses on the installations in the building. The structural engineer designs the construction, and the building physics advisor focuses on the indoor environment quality and more physics aspects. This team of advisors collaborates in the early design phases to design their part of the building. Therefore, the group influences the design of standard elements, and consequently, they are part of the design process of the utility building elements.

Barriers: the advisory team that consists of the architect, structural engineer, and building physics engineer can have objections to applying standard elements in buildings. With the application and performance of standard elements, the influence of these advisors on the project design will decrease. Furthermore, their amount of work will reduce because they do not need to design and engineer the elements anymore. Moreover, with less influence, the advisors become more unnecessary. These barriers are the key ones of all described stakeholders because the team has significant control over the current designs of utility projects.

Drivers: these advisors can have some drivers to apply and focus on standard elements. Which are to achieve higher quality, increase flexibility, and better implement techniques in the design with more quality.

Concept development team contractor

The contractor's design team does the design and engineering of the element. This team should corporate with all the stakeholders that influence the design of these standardised elements. The team designs to a technical level, implying that the component is definitive and production-ready. Thus, this team has a critical influence on the element's construction method, quality, safety, and costs. The group consists of different designers who are the lead stakeholders in the designing process.

Barriers: a barrier to designing elements with a team is that there will be a new team for each component. That influences productivity, the goals and the collaboration in the group.

Drivers: this team can develop state-of-the-art solutions, which could significantly drive this team to participate in the design process. Furthermore, the team has design freedom and should work by themselves.

Construction team contractor

The construction team is part of the main contractor of the project. This team constructs and assembles the building. Therefore, the construction processes should be safe and incorporate an easy and fast construction method of the elements.

Barriers: a barrier could be that the construction team has to assemble and construct an element by a specific method. Applying these elements in more projects and multiple times in one project raises a repetitive character in the assembling process. That could have a negative influence on the motivation of the construction workers.

Drivers: By applying more standard elements, the productivity will increase, projects will be safer, the assembly will be more accessible, and the component meets the quality and requirements of the client better. The team will answer positively by indicating these drivers to the construction team.

Management contractor

The management of the main contractor is (financially) responsible for the construction and the thereby applied elements. This responsibility covers more than economic efficiency and guarantees continuity and flow for the production and assemblage of these used elements. Therefore, the management influences decisions made during the design of components.

Barriers: the main obstacles are the organisation change that has to take place to design and develop standardised elements. Furthermore, the process does not guarantee that each component in the design process becomes ready for production, which has financial consequences. In line with this aspect, it is not clear at which moment these standardised elements make a profit for the company. Because that is unknown, the management does not risk investing in a project that does not even make it to the market.

Drivers: productivity, efficiency, safety, quality, and financial feasibility increase by applying standardised elements. These aspects are essential for the contractor's management because the current profits are not always sufficient. That can have a significant influence on the company's profit.

Supplier, subcontractor

Developing an element for the utility building industry incorporates a long collaboration with a supplier, i.e., a subcontractor. This supplier is needed because an element includes subcomponents produced by suppliers. Therefore, the subcomponent should be integrated into the element by an extended partnership. Thus, designing the element occurs most of the time in cooperation with a supplier.

Barriers: The supplier will have a contract and partnership with a contractor when applying standard elements. However, this collaboration is fragile but also essential. It is fragile because the industry is not used to collaborating for a more extended period, but it is essential to make these elements profitable.

Drivers: a significant driver for the subcontractor is to increase their company's productivity and financial feasibility. These will increase because of the guaranteed flow by the involved contractor.

The sections mentioned above indicate that stakeholders are related to the element design but are not all actively involved in designing a standard element. However, some stakeholders significantly influence the standardisation of these elements. Therefore, the involved stakeholders in the design process are the client, the advice team consisting of a structural engineer, architect and building physics engineer, then the development team of the contractor, the subcontractor, and the contractor's management.

4.3 Exchange requirements involved

This section describes and elaborates on the involved information in the design process. The study base these exchange requirements on the design of the Hutter element, of which Table 12 gives an overview. Furthermore, this study developed some exchange requirements into standard and conceptualised other requirements by applying them to develop the element. The information delivery manual in Appendix 3 describes all related data objects.

Initiative phase	Guide to choosing an element	Standardised
	List of potential partners	
	Standard overview design conditions	Standardised
	Design conditions of element	
	Functions of element	Applied
	Contract	
Schematic Design	Standard overview Requirements	Standardised
	Requirements	
	Defined construction concepts of the chosen element	Applied
	Feedback	
	Updated concepts	
	Standard trade-off matrix	Standardised
	Trade-off matrix	Applied
	SO design	
Preliminary Design	Feedback	
	Overview design parameters	Applied
	Overview of the application of design parameters	Applied
	VO design	
Definitive & Technical Design	Feedback	
	Overview values of parameters	Applied
	DO design	
	TO design	

Table 12 - Overview of exchange requirements

4.4 Actions involved

This paragraph describes the activities involving the Hutter element's design process.

Per phase, the steps are identified and shown in Tables 13 and 14. The information delivery manual of the whole standardized process is in Appendix 3, describing all these actions.

Initiative phase	Choose an element	Management contractor
	Start designing	Development team
	Search for a cooperation partner	Development team
	Contact potential partners	Development team
	Stand open for collaboration	Partner
	Decide to collaborate	Partner
	Organise collaboration meetings with a potential partner	Development team
	Attend collaboration meeting	Partner
	Define design conditions	Development team
	Define functions of the element	Development team
	Give input on defined functions of the element	Partner
	Organise a collaboration meeting with a potential partner	Development team
	Sign contract	Partner,
	Organise a design meeting as the start of the design process	Development team
	Attend design meeting	Partner
Schematic Design	Define design requirements	Development team
	Give input on requirements	Advice Team, Client
	Verification and validation	Development team
	Requirements definitive	Development team
	Organise creative brainstorming meeting	Development team
	Attend brainstorm meeting	Partner
	Define construction concepts of the chosen element	Development team
	Ask feedback	Development team
	Give feedback	Advice Team, Client
	Organise feedback	Development team
	Process feedback	Development team
	Organise design meeting	Development team
	Attend design meeting	Partner
	Update defined concepts	Development team
	Review concepts with the concept team and partner	Management contractor
	Review concepts with the client	Development team
	Identify the best concept	Management contractor
	Develop SO drawings of the concept	Development team
	Verification and Validation of SO concept	Development team

Table 13 - Overview of tasks initiative-SO phases

	Organise design meeting	Development team
	Attend design meeting	Partner
	Verification and validation of SO design	Development team
	Verification and validation requirements	Development team
	Ask feedback	Development team
	Give feedback	Advice Team, Client
Preliminary Design	Organise feedback	Development team
	Process feedback	Development team
	Indicate important design parameters	Development team
	Define how to apply these parameters	Development team
	Design VO	Development team, Partner
	Ask feedback	Development team
	Give design input	
	Verification and validation of VO design	Development team
	Organise design meeting	Development team
	Attend design meeting	Partner
	Ask feedback	Development team
	Give feedback	Client
Definitive & Technical Design	Organise feedback	Development team
	Process feedback	Development team
	Find appropriate values for parameters	Development team
	Design DO	Development team, partner
	Ask feedback	Development team
	Give design input	Advice team
	Verification and validation DO design	Development team
	Delivery of final DO design of the element	Development team

Table 14 - Overview of tasks VO-DO phases

4.5 Proposed design process

This section focuses on the content of the proposed design process developed in this chapter.

4.5.1. Windows Microsoft Visio

This study uses the software of Windows Microsoft Visio to create the design process. The software is known in the industry and fits the requirements for developing a process map. The company of Royal BAM Group offers the software.

4.5.2. Process overview

The design process of utility building elements consists of the following indicated steps. These steps are shown in Figure 34, which gives an overview of the design process. This Figure indicates twelve essential steps of the design process. The left column of Figure 34 demonstrates the critical input needed to make design choices. The coming paragraphs elaborate on the twelve steps and the input.

Furthermore, the study divides the design process into four main project life cycle phases applied in the industry. The research uses these phases to indicate the progression of the design process. The following section discusses why each step is part of one of the phases. Furthermore, after the explanation of the twelve steps after the framework involve codes that relate to the coding of the tasks in the BPMN process map.

These steps are explained by having the Hutter element as a reference to identify and discuss each step. By taking this element as a reference, the explanation is better to follow, and the context of the steps is clear.

The following stakeholders are identified:

- **The Client:** The client is the financial owner and client of the whole project where an element can be applied. The client influences the design of the building because it uses the building and pays for it. Therefore, this stakeholder is essential for developing standard elements. Thus, in the design process, potential clients for future projects are approached to give input during the design.

- **The Subcontractor:** The subcontractor is the potential collaboration company that supplies an essential part of the element. Therefore, the partner influences the element's design because that company could produce it. Thus, this stakeholder is critical in the creation of standard components.

- **The Advice Team:** The advice team consists of three advisors: the architect, the structural engineer, and the building physic engineer. As stated as critical during this study's interviews, these advisors are involved because by the developing of standard elements; the concept team takes over some work of these advisors. Thus by involving these advisors, the concept team covers the aspect of claiming some part of their work. Furthermore, the advisors have specific and essential knowledge that the concept team should implement.

- **The Concept Development Team:** This team consists mainly of the contractor's engineers and could include some engineers of the potential partner. The group focuses specifically on the development of these elements and has, therefore, the main tasks of this design process. The team contains 4 to 5 engineers in the end and should not be too large. Moreover, this team is the primary user of this standardised process.

- **The Management of the Contractor:** The contractor's management influences the concept development team and is, in the end, responsible for their results. Therefore, the process map includes the managing board in this design because they make essential decisions during the process.

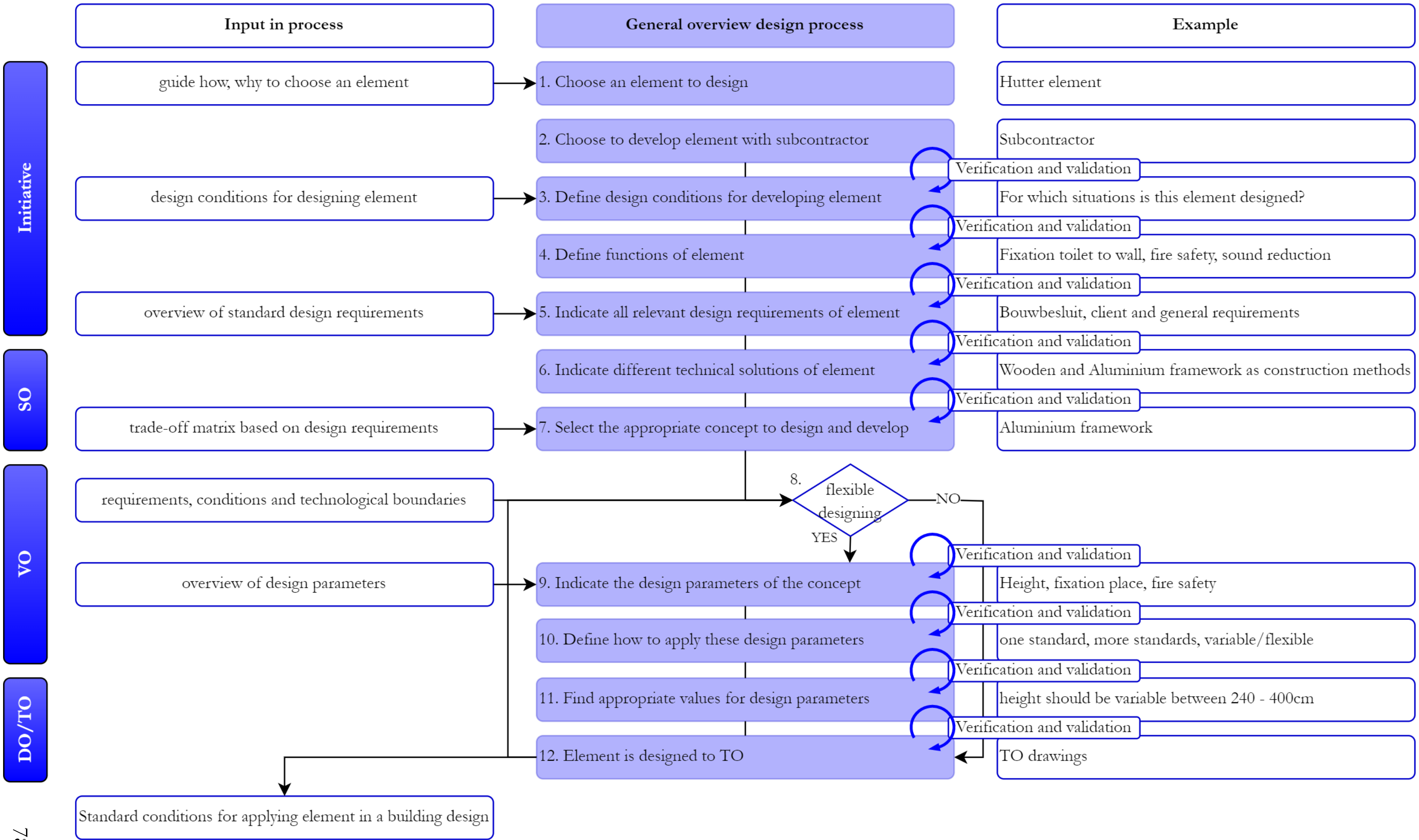

Figure 34 - Overview design process

Step 1	**Choose an element to design** Importance: ★ ★ ★ ★ ★
Map Code: 1.01	This step focuses on choosing an element to develop and design. According to a small framework, this decision convinces the contractor to build and create a component. It is essential to state that this decision is necessary because it illustrates the contractor's commitment and responsibility when it chooses to develop a concerning element. The study proposes a workflow to identify if the component meets the critical requirements. Thereby, it is possible to make a thorough decision.
	Concerning the Hutter element, the contractor decides at some moment to develop and design that element with a partner.

Step 2	**Gateway: develop with subcontractor** Importance: ★ ★ ★ ★ ★
	This action involves the decision to develop and design with a subcontractor because the contractor creates some elements in-house and other elements in collaboration with a subcontract that supplies an essential component.
	The contractor designed the Hutter element in collaboration with another company. This company delivers the standard water toilet reservoirs and toilets themselves. Therefore, it is critical to collaborate because the subcontractor influences the component's dimensions that impact the element's design. Thus, the contractor executed a more extended collaboration with this supplier. Moreover, the production of the parts occurs with the supplier.

Step 3	**Define design conditions for developing an element** Importance: ★ ★ ★ ★ ★
Map Code: 1.08	The third step implies that the developmental team indicate and identifies the design conditions. These design conditions determine how and when the contractor can apply the component in projects. In other words, the game rules define how to tackle the design problem. These conditions indicate where the element performs, what type of dimensions it has, and how the contractor can apply it in a building.
	Some design conditions for the Hutter element are that the component should be applicable in all toilet rooms of new realised offices, hospitals, and schools before the contractor designed the aspect. By applying the component in multiple types of buildings, the technical and functional requirements change and the complexity increases.

Step 4	**Define functions of the element** Importance: ★ ★ ★ ★ ★
Map Code: 1.09	At the end of the design and development of the element, it should meet the functional requirements. However, the process bases these requirements on the functions the part should perform. These practical functions influence how the contractor designs the element and which choices they can make during that process. Therefore, it is essential to state, define, and elaborate on the element's practical functions during operation.
	The critical functions of the Hutter element are the fixation of toilets, toilets or closets to the wall. Furthermore, the fire safety increases and the acoustic influence of the toilets decreases. Moreover, the element has the function of an extra layer and thereby increases the isolation values of the building.

Step 5	**Indicate all relevant design requirements of the element** Importance: ★★★★★
Map Code: 2.01	After defining the design conditions and function of the component, the process should indicate and explain the requirements. Therefore, this process uses a standard list of requirements based on the requirements of the Hutter element. A difference between requirements indicates three general types, law and regulations, BAM requirements and client requirements.
	Many different requirements define how it should perform during operation for the Hutter element. For example, the technical specifications from the NEN indicate what kind of forces the part should consider or what type of fire safety requirements should the element meet. Then, clients want to have increased quality and functional design. Furthermore, the BAM design requirements focus on production requirements. The next chapter elaborates on all these requirements.

Step 6	**Indicate different technical solutions of the element** Importance: ★★★★★
Map Code: 2.07	In this step, the team identifies the different available technical solutions for the element. These solutions imply the technological applications currently performed in the industry and are possible directions for developing the component to standard, modular, and parametrically. The team can determine suitable manufacturing and prefabrication solutions based on these applications.
	The Hutter element has different technical applications. One of these applications developed the team into a component. The applications were a framework of aluminium and a framework of wood. Therefore, the team identified these two as current applied concepts.

Step 7	**Select the appropriate concept** Importance: ★★★★★
Map Code: 2.18	This step focuses on selecting the appropriate technical solution, i.e., concept, to design and develop. This step consists of performing a trade-off that the process supports by a standard trade-off matrix. The matrix gives an overview of the BAM requirements and the different identified technical solutions. The table tests each solution to each of the BAM requirements. The answer, i.e., the concept that meets the requirements the best, is the concept that is selected to design and develop into an element.
	The team developed the framework of metal into a standard element. The team chose metal because that application offers the best practical solutions concerning the defined requirement. The material and technical applicability are easy to redesign to the preferred situation.

Step 8	**Gateway Flexible Designing**	Importance: ★★★★★

During this step, the team decides for each part of the element to design that part flexible or not. This flexible design decision implicates creating a part in multiple variations or fully adjustable between a parameter range. That is necessary for this design process because the team decides if it wants to design a parameter or feature flexible. That implies that the team selects the standards in this decision. By applying more standard features, the more standard the element becomes. Therefore, it becomes more efficient, easier to produce, and more guaranteed quality than elements with many flexibilities by parameters.

The element's height is a part of the element that the team should design and is a critical parameter. The height of the Hutter element should fit the design conditions and requirements stated earlier in the process. From these conditions, the team extracts the component to be applicable in multiple types of buildings, offices, schools and hospitals, and 80% of the construction projects of Royal BAM Group. The current projects of Royal BAM Group related to the identified type of buildings have different heights. Thus, the height should be flexible in applying the element in a minimal 80% of the projects. Otherwise, the contractor does not meet one of these essential conditions.

Step 9	**Indicate the design parameters of the concept**	Importance: ★★★★★

Map Code: 3.08

This step focuses on indicating the concerned parameter that the team should design. That implies defining the context that incorporates the parameter, so defining precisely the beginning and end of the concerned parameter.

For example, the team identified height as a parameter of the Hutter element because the element should be applicable in multiple building types that vary in height per floor. The element's height is between the structural floor and the structural ceiling, wherein the component should be applied.

Step 10	**Define how to apply these design parameters**	Importance: ★★★★★

Map Code: 3.09

While action 9 defines how to apply the parameter, this step indicates the variations in how the team can apply the parameter. These choices are 1) one variation; 2) multiple variations; 3) flexible between an interval of values. The three choices are the possibilities of how the team can apply a parameter in the design of the element.

The height of the Hutter element should be flexible between an interval of values. That is the best approach for designing the component's height, seeing that the element should be applicable in multiple building types with different heights according to the design conditions. By having one or multiple variations determined, the flexibility for applying the element decreases drastically and is therefore not a good possibility.

Step 11	**Find appropriate values for design parameters**	Importance: ★★★★★

Map Code: 4.08

This step implies finding the specific appropriate values for the concerning parameter, wherein step 10 indicates the ideal approach.

Thus, the team of the Hutter element proposes to design the height flexible between an interval of values. This step identifies the values that determine the specific characteristics of that parameter based on the conditions and requirements in this step. The Hutter element should fit between these two structural elements with a minimum height of 2400m and a maximum height of 4000mm.

Step 12	Element designed to DO/TO	Importance: ★ ★ ★ ★ ★
Map Code: 4.12	During this step, the team designs the parts and parameters of the element to definitive and technical design (DO/TO). Thus the technical solution, i.e., the application of the parameters, is designed based on the input of the requirements.	
	The height should be flexible between 2400mm and 4000mm for the Hutter element. Therefore a technical solution should be developed that can be flexible between this interval.	

Verification and Validation

An essential action during the design process that the team should perform many times is verifying and validating the design. As stated in Figure 34, this action occurs after each step which is more elaborated below.

Verification: the moment to execute a comparison between the design decisions made and the design requirements, seeing if there is alignment between the design and the requirements.

Validation: discussing the design results with the client and relevant stakeholders to discover if the design meets the client's requirements and desires.

- **After each step:**

After each step, verification occurs by verifying if the decisions and design choices align with the design conditions and requirements.

Validation with the customer and other stakeholders occurs by discussing the current versions of the drawings and decisions made during the design process.

- **At the end of each design phase:**

The design validation and choices made during the design process at the end of each phase occur by contacting the advice team, individual, and the client. Then the design team asks these stakeholders for feedback on the choices and design, which translates to an updated design.

Verification occurs by checking and verifying the results concerning the stated design conditions and requirements. This action is the same as the action at the end of each step of the design process. This verification takes place many times.

4.5.3. Subprocess Initiative Design Phase

This Initiative Design phase incorporates creating the context wherein the elements should be designed. This context indicates the corporation partner, the design conditions, the functions of the components, and the component's requirements. Figure 35 gives an overview of the Initiative Design Phase.

This initial design phase is needed to create a context wherein the team can apply each designed element. The context implies the boundaries of these elements and is therefore essential. Creating the context and choosing the element are the first tasks related to developing a component. Thus, the study defines this phase as the initial design phase.

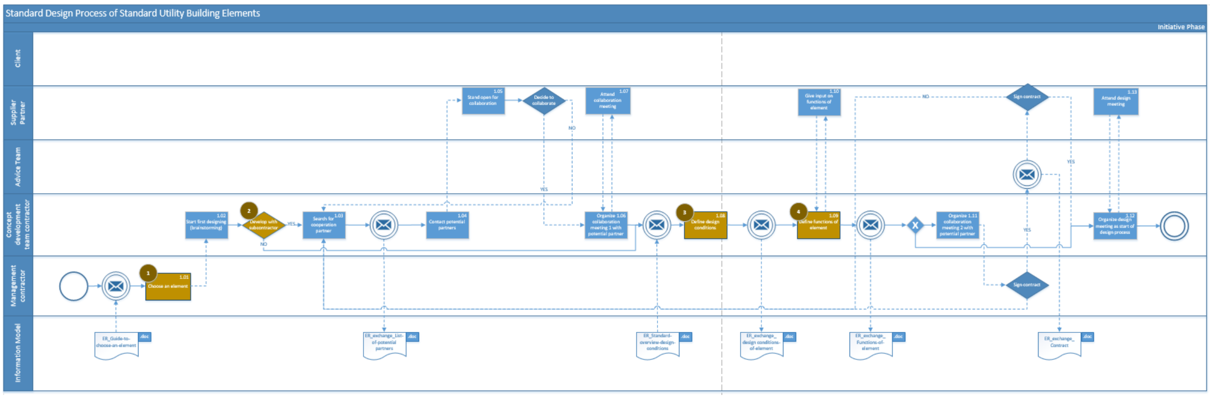

Figure 35 - Overview Initiative Design Phase

Start of Initiative Design Phase: The task that when the design team chooses an element to develop to standard. The team bases this decision on a workflow created by this study

End of Initiative Design Phase: This phase ends with the meeting where the design team creates the first input. That describes the next step where different concepts are developed.

The main objectives of the Initiative Design Phase are the following aspects:

1. Choosing an element
   This task focuses on choosing the element to develop. To this structurally, a workflow is created that gives a method to guide in deciding which component the team should design. The next chapter elaborates on this workflow.

2. Collaboration with a partner
   During the initial phase, the contractor creates a collaboration when they need it to develop the concerning element. The tasks related to developing this collaboration are essential and part of the initial phase.

3. Indicating the functions of the element
   Another significant action in this phase is defining the elements' functions when used during operation. Thus, what does the component add to the building and the usage by end-users? This question should the design team answer to indicate the functions of the element.

4. Indicate the design conditions of the element
   The last essential task is defining the design conditions and the game rules for designing and developing the element. These conditions determine where, how and why a component should be applied.

The initiative phase involves the next exchange requirements:

1. ER_Guide-to-choose-an-element
2. ER_List-of-potential-partners
3. ER_Standard-overview-design-conditions
4. ER_Design-conditions-of-element
5. ER_Functions-of-element
6. ER_Contract

Furthermore, no reiterations take place in this subprocess.

4.5.4. Subprocess Schematic Design Phase

This schematic design phase is the second phase of the overall design process of elements. During this phase, different concepts are created based on the context developed in the initial stage, which are the bases for developing one of these concepts to a standard element. Figure 36 gives an overview of this phase.

The phase is essential as a consequence of the initial phase because this phase focuses on different construction solutions currently applied in the industry. These technical applications are defined as concepts which are the bases for choosing one of these for further development. Therefore, the study defines this phase as the schematic design phase.

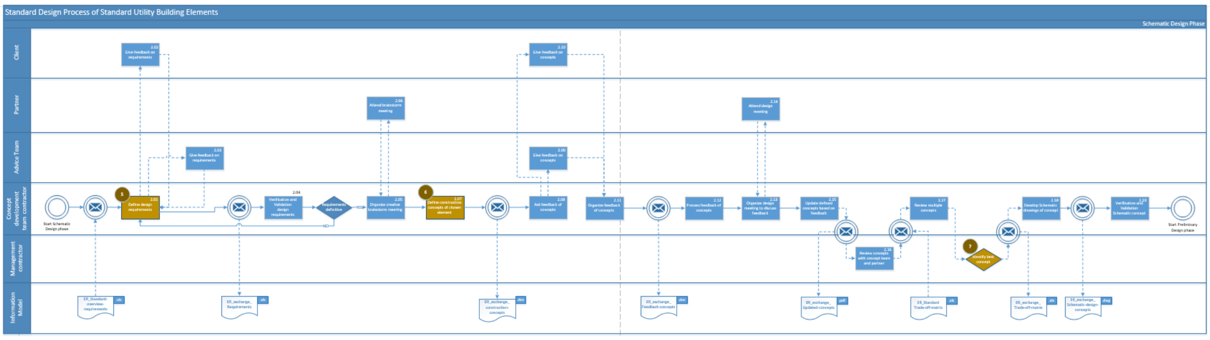

Figure 36 - Overview Schematic Design Phase

Start of Schematic Design Phase: This phase starts with the indication of design requirements, conducted by the design team that uses a standard overview of requirements as bases.

End of Schematic Design Phase: This phase involves validating and verifying the first conceptual drawings of the chosen concept, conducted by the design team.

The following aspects are the essential tasks of the schematic design phase:

1. Indicating design requirements
The design team develops design requirements as the first task of the concept design phase. These requirements define what the element should meet and do. There are three types of requirements: law and regulations, generic requirements, and client requirements.

2. Indicating different concepts
During this task, different constructional solutions are indicated that are currently applied in the industry of the concerning element. These solutions, i.e., concepts, are part of the design process because the development team generates different perspectives on potential solutions.

3. Develop these concepts

These should each be developed into concept design when the design group indicates concepts to get a more structural view of these concepts.

4. Choose one of these concepts

The last step with these concepts is choosing one of the concepts to develop into a standard element. Therefore, a trade-off matrix is used, which is performed based on the matrix. The trade-off occurs between the concepts, wherefore the generic requirements defined in the initial phase serve as conditions for the trade-off.

This subprocess involves the following exchange requirements:

1. ER_Standard-overview-requirements
2. ER_Requirements
3. ER_Defined-construction-concepts-of-chosen-element
4. ER_Feedback-concepts
5. ER_Updated-concepts
6. ER_Standard-trade-off-matrix
7. ER_Trade-off-matrix
8. ER_Schematic-design-concepts

Furthermore, the following reiterations take place in this process:

1. Feedback on requirements by the client
2. Feedback on requirements by advice team

4.5.5. Subprocess Preliminary Design Phase

The third phase of the design process consists of the Preliminary Design. The development team designs the chosen concept into preliminary design during this phase. Figure 37 gives an overview of the initial design phase.

It is an essential part of the overall design process because, during these steps, the element's design starts and the first parameters are chosen and developed into schematic design. It is a phase that incorporates the more designing part of the overall process and is relevant.

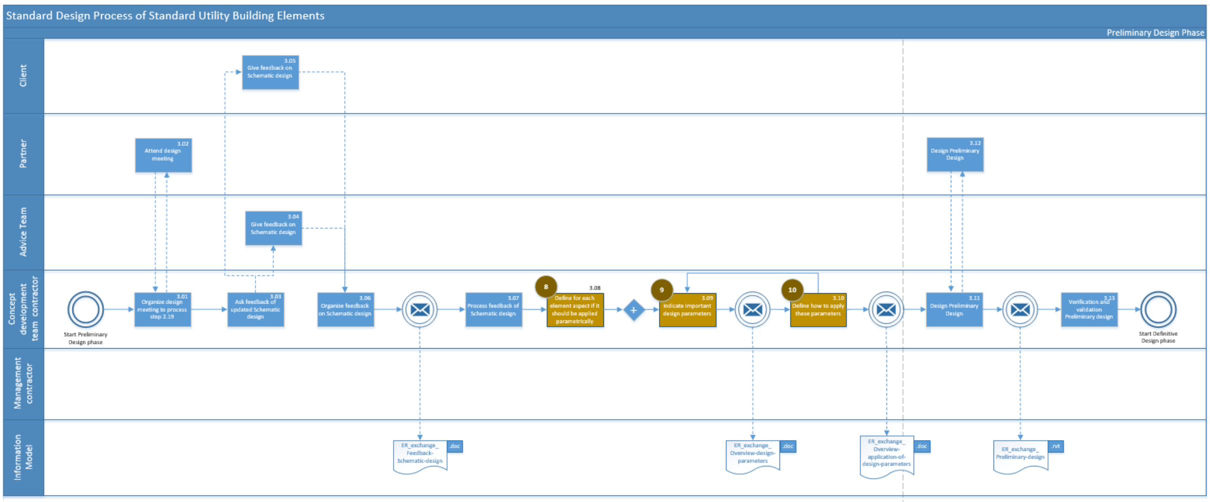

Figure 37 - Overview Preliminary Design Phase

Start of Preliminary Design Phase: a design meeting indicates the start of this phase. This meeting incorporates the beginning of the designing of one element to standard.

End of Preliminary Design Phase: the end of this phase is described by verifying and validating the preliminary design created. The design team can use the verification and validation output to develop the preliminary design to the definitive design.

During this preliminary design phase, the following tasks are essential:

1. Verification and validation
   An essential task during the further development of the chosen concept is verifying and validating with stakeholders and the defined requirements. In the end, the developed element should meet all these aspects.

2. Define to design flexible per parameter
   During this action, per parameter is defined if it should be applied flexible or standard. The development team designs the parameter in multiple variations with flexible design.

3. Indicate parameters
   When the design team designs a parameter flexibly, it is essential to create a thorough definition of the parameter and which other aspects of the element it influences. This action will help make a specific decision on how to apply the parameter.

4. Define how to apply the parameters
   This task focuses on how to apply the concerning parameter. That could be standard in multiple variations or complete flexibility between certain intervals. This flexibility is used when the parameter has significant variations in different applications in buildings.

Furthermore, the following exchange requirements arise in this preliminary design phase:

1. ER_Feedback-VO
2. ER_Overview-design-parameters
3. ER_Overview-application-of-design-parameters
4. ER_Preliminary-design

Reiterations take place in this phase:

1. Design brainstorm meeting
2. Indicating and defining parameters

4.5.6. Subprocess Definitive Design Phase

The final design phase is the last phase of the design process for the utility building element. During this phase, the design team develops this schematic design into the definitive and technical ready design. The component is definitive and designed according to the design conditions and requirements of the stage.

Figure 38 indicates the DO phase, which is an essential part of the design process because it shows the last phase where all parameters and designs are made definitive. Furthermore, verification and validation are crucial.

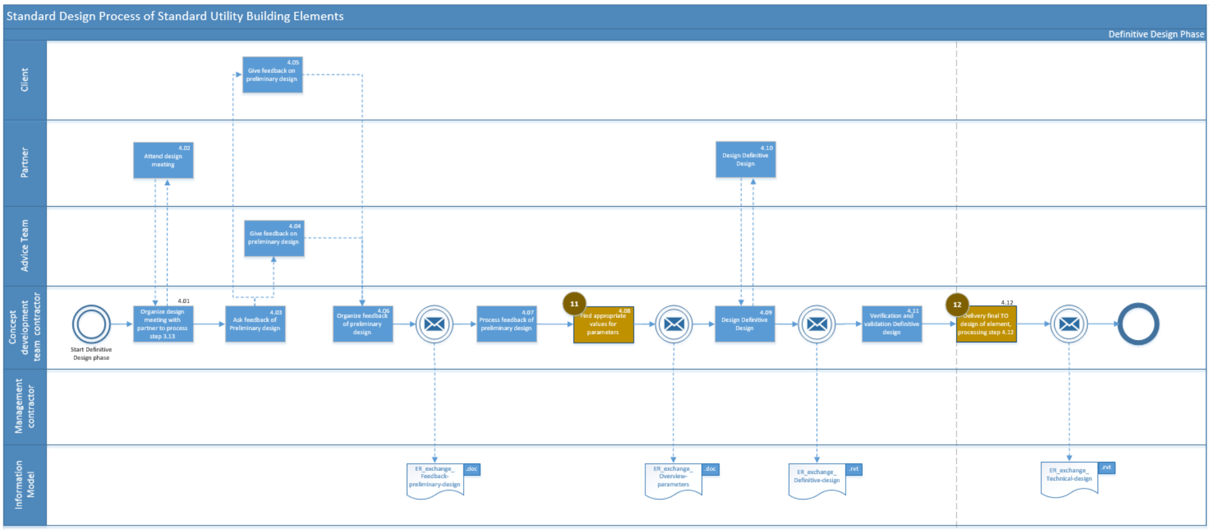

Figure 38 - Overview Definitive Design Phase

The start of the DO phase includes a design meeting where the VO design's verification and validation input is discussed and verified with the critical stakeholders.

End of DO phase: the technical design that implies the design that incorporates all technical characteristics of the element indicates the end of this phase.

During this phase, the essential tasks were the following:

1. Verification and validation

   During this last phase, verification and validation are essential because the design is increasingly definitive. The design choices made, are definitive and thus should be done well according to the requirements and stakeholder perspectives.

2. Defines values for parameters

This task focuses on the final values of the parameters defined and elaborated in the schematic design phase. The design team indicates specific values for the application of a particular parameter.

3. Design to the definitive and technical level

After all, the team made all design choices during the design process. Thus, the design should be developed into a definitive design and, in the end, into a technical design. With this action, the element's design becomes increasingly specific, needed to produce these elements.

The following exchange requirements are involved in the final design phase:

1. ER_feedback_preliminary-design
2. ER_Overview-values-of-design-parameters
3. ER_Definitive-design
4. ER_Technical-design

Furthermore, there are no reiterations during this phase.

4.5.7. Interpretation of requirements

During the proposed design process, the interpretation of the requirements is an essential part of the process. The interpretation defines how the team designs the element and how they make choices. Furthermore, the study identifies design interpretation and design management as challenges in the literature study. Therefore, it is essential to discuss this part more in-depth.

Figure 39 indicates how the interpretation of the defined requirements occurs during the design and development of elements for the utility building industry. First of all, for each requirement, a decision makes the difference in flexible designing, yes or no, which indirectly implies the question of designing parametrically to solve the concerning design requirement. If yes, then a process of three steps defines how to create that requires flexibility and thus parametrically. That consists of first identifying the appropriate parameter and then describing how to apply that parameter and the values. The team can use a parameter from three perspectives: 1. One standard; 2. Multiple standards; 3. Fully flexible between an interval.

When a requirement is not designed flexible, one technical solution performs that requirement. After both sections, a verification occurs to indicate if the requirement is solved appropriately.

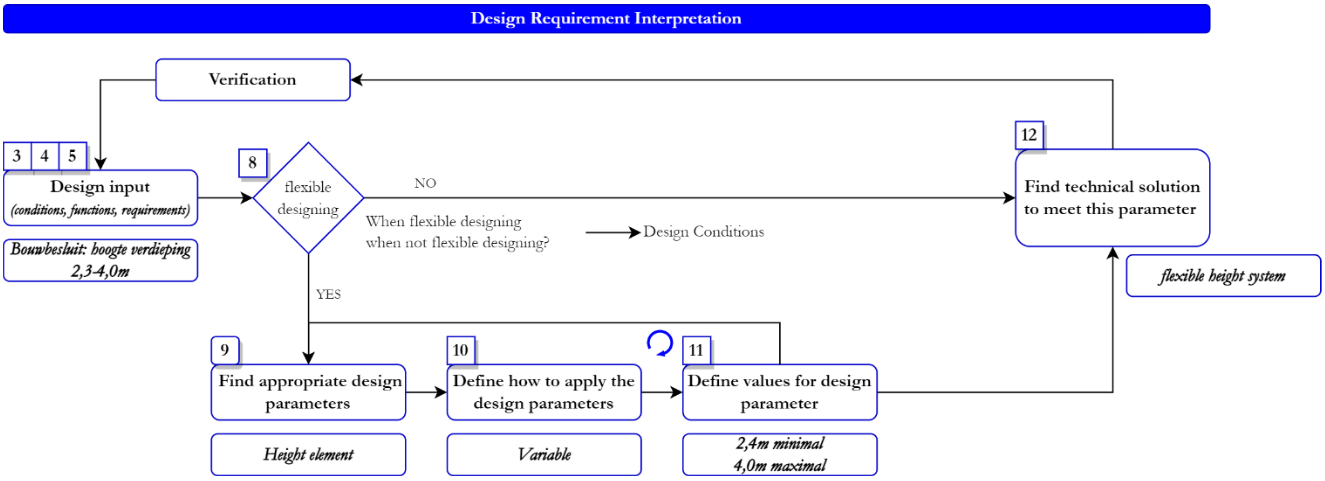

Figure 39 - Overview Design Requirement Interpretation

4.6 Validation

This section elaborates on the validation this study performed for this proposed design process. Validation is essential because that underlines how and if the proposed artefact can perform in the context of Royal BAM Group. To validate the process the research organised a panel discussion and made a comparison of the process with a designed element within BAM, which is the distribution rack.

4.6.1. Panel discussion

The panel discussion is organised to validate the proposed design process with experts from Royal BAM Group. The following paragraphs describe the discussion's goal, experts, approach and conclusion.

This discussion occurred to validate the proposed design process. This discussion aimed to discuss if BAM Bouw en Techniek can easily apply the design process. Furthermore, to validate if the structure and content align with the practical field. Moreover, if the content and structure are readable and understandable, these three assumptions were the goals of this panel discussion.

For this panel discussion, three experts from Royal BAM Group attended the panel. These three experts had different expertise and were therefore relevant for the discussion. The first expert is a design manager responsible for the design management of larger utility projects, the second expert is a specialist in the innovation of processes and products within the company. The third expert is responsible for the development and maintenance of an element, the distribution rack, within BAM Modulair. These three experts are relevant for this design process because they know how it could and should be implemented concerning the current practical situation. Furthermore, they offer technical knowledge and expertise, know how to deal with other stakeholders and have a conceptual view of processes.

Structure and design of process:

1. *Do the twelve steps include the whole design process?* According to the discussion the process includes the primary necessary tasks. This implies the proposed process works and is complete. Therefore, no changes are made based on this input from the experts.
2. *Fits the process in the context of the utility building industry?* The process fits in the context of the utility building industry, however, the design phases included in the design process make it hard to relate it to the main design process of projects. With the phases included in the design process, it seems that this process is performed parallel to the project life cycle phases. Consequently, the experts proposed to remove the four phases from the design process, so it does not overlap with the project life cycle process. However, it is chosen to not remove these phases and include these, because by explaining the context the purpose of the process should be clear and the phases indicate how the design is going according to this structure. Because all construction experts know these phases, these give a good indication of the progress of the design process.
3. *Are parametric, modular design and standardisation enough included?* The experts state that standardisation and parametric design are enough included in the design process. However, modular design as a concept is not specifically included in the process and should be more visible and explicitly included. Therefore, the experts propose to include the concept in the design condition part, where the dimensions and context of the element are elaborated before designing. These aspects are in line with the modular design characteristics. Consequently, the design conditions are changed according to this input.

Content of design process:

4. *Are verification and validation enough guaranteed in the process?* The experts state that the validation and verification are well guaranteed in the process, however, the difference between the two concepts is not enough discussed. There could be a better discussion and description of the two concepts, therefore, this input is taken into account. In chapter 4.5.2. more is elaborated.
5. *Is the difference between the design conditions, requirements and functions clear?* According to the experts the three identified inputs, the design conditions, functions and requirements, are well defined. However, the difference between requirements and functions could be made more explicitly, because a function leads to a requirement. This difference between the two is essential to indicate.

Implementation and performance of process:

6. *Support the structure enough for implementing the process?* The current design and structure give enough support for performing the process, the structure is clear and the twelve steps are explicitly structured.
7. *Can the process easily be implemented?* The experts state the process can easily be implemented, however, the research indicates more requirements that should be met to enhance this process. According to the research, these requirements are the need for another mindset and organisation. Consequently, the contractor can easily implement the process but with taking the context into the account this implementation is a major challenge.

The panel discussion lead to different input related to the three approaches, some input is processed in the research and some input is not. Consequently, the discussion lead to a stronger and validated process that is ready for use by larger contractors.

4.6.2. Distribution Rack

To make the proposed process better and more improved, an extra validation step is taken in the form of the comparison of an element with the process. This element, the distribution rack, is an element the company already develops and produce and is, therefore, a good example to compare the process with.

This validation occurred through multiple meetings with the head designer of the distribution rack, by asking and discussing the design process concerning the rack the following recommendations and validation are made. The different input is evaluated and based on the available information the following conclusions are made. A conclusion from the meetings is that the available information about the element and the record of the design process is not complete and structured. Therefore, most of the input stated in the proposed design process is not explicitly available and choices made during the design process of the rack can not be found. A consequence is that the current rack is designed according to principles and argumentations that are not available and therefore the following recommendations are stated:

1. Create a structured argumentation about why the distribution rack is chosen to develop.
2. Make a more structured overview of the related design conditions according to the proposed design conditions from the design process.
3. Make an explicit overview of the relevant design requirements.
4. Indicate when the element can and cannot be applied.
5. Make an overview of the made design choices, and ensure the design information.

According to the available information about the element, the contractor clearly states the parameters and functions of the element. Thus the design conditions, choices made and requirements are essential aspects to focus on for enabling more standardisation of the company and the element.

4.7 Incorporating barriers, benefits, challenges and design concepts

This section focuses on how the research implemented the gathered knowledge of the literature study and interviews into the design process. It is essential to make a relation between the first part of the research and the second part, the developing section.

Barriers

The design process includes the primary barriers: 1) organisation; 2) stakeholders; 3) process; and 4) strategy. The process includes the first barrier by developing an Information Delivery Manual that describes the whole design process and the related organisation aspects, this IDM enables a concept organisation that is needed for developing standard elements. Furthermore, the process includes stakeholders with an approach that positively asks the stakeholders for influence, and the process states how to approach and include the stakeholders. Moreover, the process includes the sub barriers of the process barrier focusing on involving manufacturers, making essential decisions at an optimum time and initiating a manufacturing production of the developed element. At last, this study and the proposed process have a positive influence on the strategy of BAM Bouw en Techniek by generating recommendations for the implementation of standardisation in the company.

Benefits

The process includes the primary benefits of standardisation, which are the following process approaches: 1) technical; 2) on-site; 3) organisation; and the following product benefits: 4) time; 5) quality; 6) technical. By performing this process the company experiences process benefits with a more structured and measured construction process and site, furthermore the process positively influences by the increased productivity through familiarisation. Also, the quality of the products that the company sells increases, and the process influences lead-in times positively, and minimises overall project time and the reduction of waste.

Challenges

The process incorporates most of the defined challenges of this research, which are: 1) implementation; 2) quantification; 3) mindset stakeholders; 4) mindset designers; 5) planning; 6) collaboration; 7) contracts; and 8) flexibility. This study created recommendations for the implementation of the process and thereby incorporates this challenge. Furthermore, the process includes the challenges planning, collaboration and flexibility. By focusing on the 80/20-rule, and designing with a stakeholder. However, the mindset of all related experts in the design process is not taken into account and should be studied in further research.

Design concepts

The process incorporates and includes the three relevant design concepts: standardisation, parametric design and modular design. The process applies standardisation by designing according to the predefined design conditions and by developing this process in standard format. This process is standardised so that for all kind of elements the same approach can be used which generates a learning curve within the concept organisation. The process includes parametric design in step 8 of the process, where the design team decides if an element part should be designed flexible. And, modular design is incorporated by the developed design conditions that focuses on the context and dimensions of the element and including the concept as requirement in the design process.

4.8 Conclusion

The study bases the creation of the design process for standard, parametric and modular elements for the utility building industry on the input of the literature review and interviews. Furthermore, the research takes the Hutter element as a reference.

The main benefits of standardisation are applied in this design process, focusing on a standard procedure that enables a working guideline that is the norm within the company. That generates more value by increasing productivity and efficiency.

The proposed standard design process tackles the main barriers to standardisation. A reorganisation should occur to perform the proposed process well because the contractor should create a concept team that designs and develops these elements. Thereby, an entire project team is committed to standardisation. Furthermore, the process makes decisions at a good time, involves stakeholders, incorporates the clients' views, and the contractor takes the first steps in the manufacturing industry with this design process. Besides tackling these barriers, the process tackles the following challenges: collaboration, mindset, flexibility, and quantification. The process tackles the challenge of partnership because this process proposes to work together for a more extended period. The attitude of the designers and stakeholders will change because the goal is to develop a standard element. This change goes gradually and starts with applying this process structurally. The process tackles flexibility by incorporating this challenge in the design process with the decision to design flexible or standard per parameter. Furthermore, the quantification of standardisation will increase with the application of this process because it becomes easier to quantify the benefits of the traditional way of working.

Furthermore, the process incorporates the three design principles central to this research. First, it performs standardisation by generating a standard procedure that the contractor should perform during the development of elements. The designed component becomes standard because the design team create it according to the proposed design process. That team achieves this by creating some parts flexible to the element and other parts standard. Secondly, the team designs it parametrically by applying a decisive moment in the design process where each element part, i.e., parameter, is defined if it should be designed flexible or standard. Third, the process and element become modular by applying these to the design conditions and requirements that the team should consider.

5 A case study: the conceptualisation of the standardised design process

This chapter conceptualises an element according to the proposed design process. This conceptualisation is applied to indicate if the design process is applicable in the industry, and therefore this chapter is executed as validation of the proposed design process. According to the design process, the essential data objects, i.e., standard input, is developed and analysed using the Hutterelement. These critical inputs are the standard conditions, design requirements, a decision matrix, design parameters and the indication of the triggers to apply this element in construction projects, as indicated in red in Figure 40.

This element, the fixation framework of toilets in a metal stud wall, was developed within Royal BAM Group with a partner some years ago. However, this project is applied in some projects but never used anymore by the contractor. By applying this element as a reference in this research, the study has the primary technical information of that design available. Therefore, the focus is more on conceptualizing the design process and the information that is not yet available on the element. The study uses the information available of the component to translate to the structure proposed by the design process. Furthermore, the study uses the available information as a reference for developing the proposed design process.

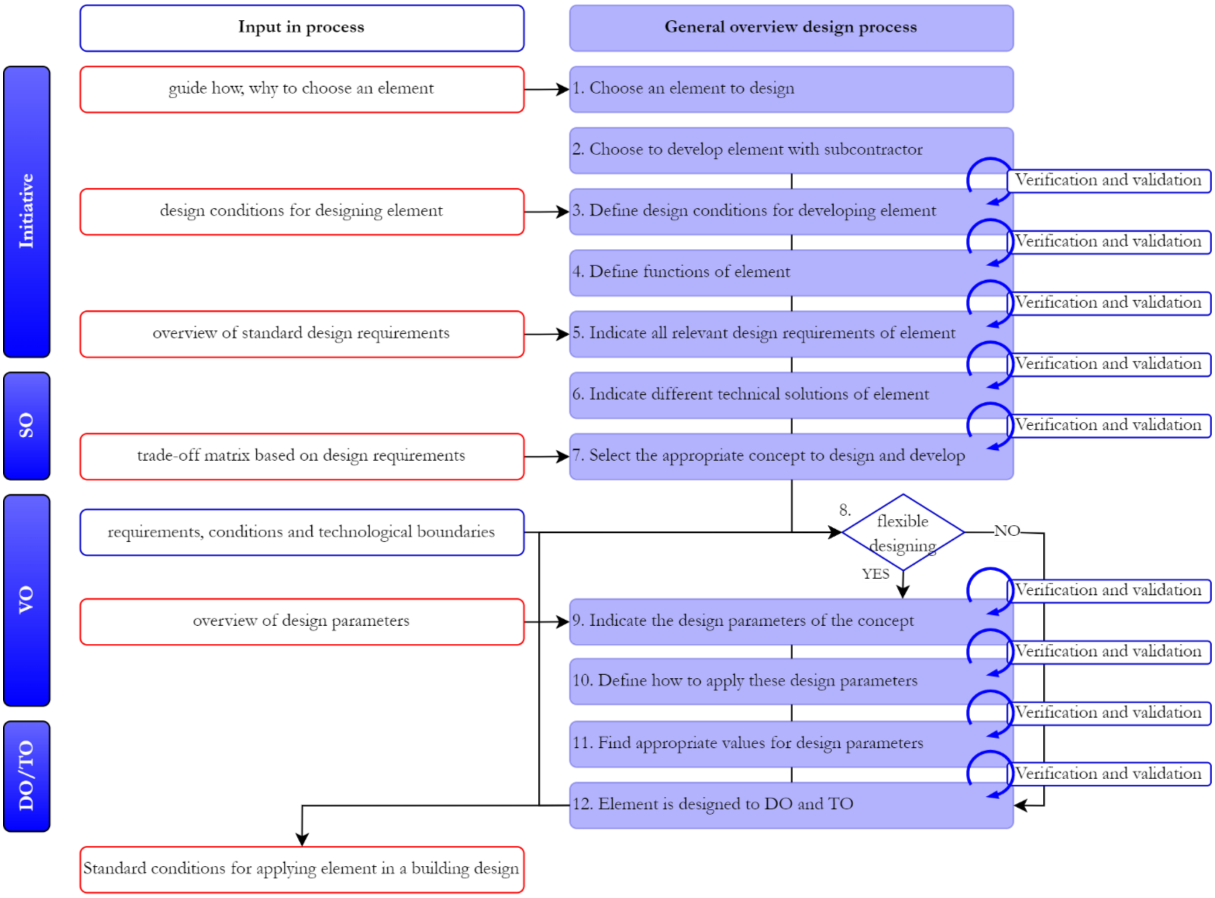

Figure 40 - Overview essential standards for design process

5.1 Choose an element to design

This section elaborates on how a contractor should choose an element for conceptualisation and how to choose other relevant components to start the design process. First, input for this workflow is identified and elaborated. Then the proposed method is embroidered and applied in this conceptualisation chapter of the Hutter element.

According to the interviews, installations are the essential elements that a contractor can develop. The experts indicate this element as the most promising building component to develop into standard, parametrically and modular elements. The decision answers this request because the Hutter element is as an installation. Furthermore, the interviews state that productivity is essential in developing an element. The experts focus on productivity, which generally focuses on efficiency. Efficiency in better financial results is a significant aspect the industry focuses on, and the construction time efficiency should increase.

The workflow in Figure 41 is a result of the input from above.

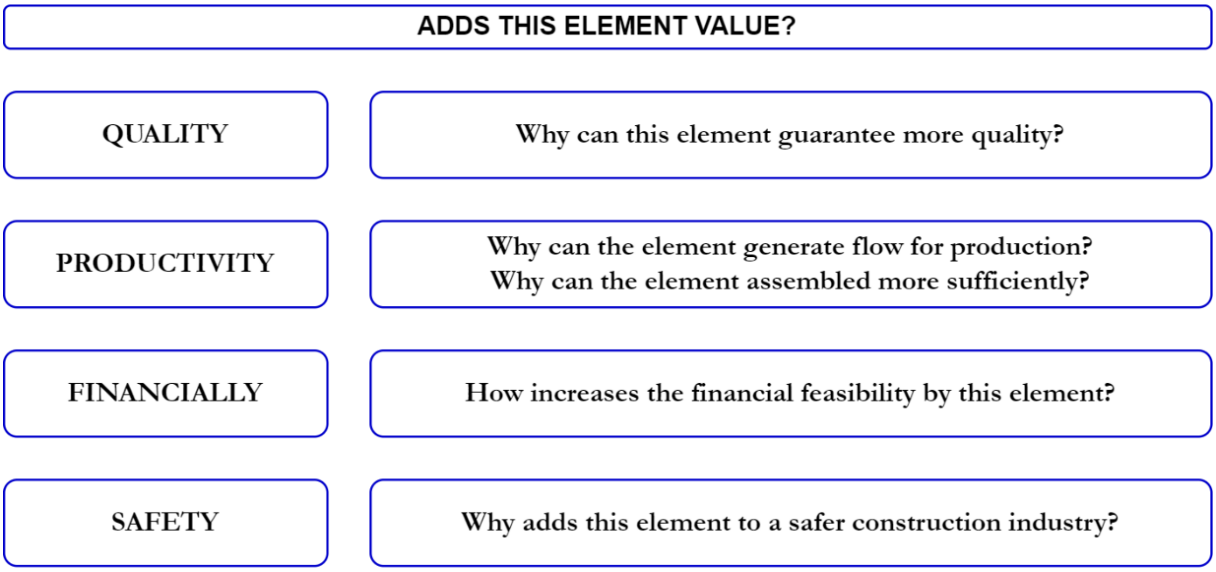

Figure 41 - Checklist standardisation element

According to the literature review, the main goals of standardisation are to increase the quality, productivity, safety and financial feasibility. According to the literature study conducted in this research, these four aspects are essential in enhancing the standardisation movement. Because the focus is on these four aspects, standardisation can be seen as an approach to reaching an industry with increased quality, productivity, safety, and financial feasibility. Therefore, these four aspects are the basis for this workflow.

Quality

Quality is an aspect which has multiple reasons why the research includes it in the workflow. First of all, quality is essential in creating more customer value. The customer value will increase when the guarantee of the element is more extended, the performance is better, and the solution is an answer to the customer's problems instead of custom-made construction solutions. The contractor can increase the quality from many perspectives. However, the central quality aspect is to increase the performance during operation. Focusing on higher performance will demonstrate the quality as stated according to the interviews of this research.

Hutterelement: The contractor can guarantee more quality by standardising the element because the final result is known.

Productivity

The second primary purpose of applying standardisation is to increase the productivity of the utility building industry. Productivity is essential in the reasoning why the sector is lagging behind efficiency concerning other sectors. The industry designs still utility buildings that are project-specific, while project ascending production of elements generates a higher efficiency and productivity. Standardisation of elements should increase the productivity of the utility building industry. Therefore, it is a pillar in developing the correct elements. That translates to whether there is enough flow for production and construction to make it efficient and if the contractor executes the assemblage more efficiently.

Hutterelement: Yes, it does. By applying it at 80% of all utility projects of BAM and by standard assemblage process.

Financially

The construction industry, in general, needs to increase the financial feasibility because that is within projects not always sufficient due to most reasoning of a contractor is economically focused. The options made in all construction processes are mostly financially driven. The focus on standardisation is either financially driven because standardisation should increase the financial performance. Therefore, a higher economic performance focuses on standardisation, which is why this study considers this.

Hutterelement increases financial feasibility by higher design, production, and assemblage productivity.

Safety

Another central pillar in the construction industry is safety. Safety is one of the main subjects in multiple strategies plans, as it should increase in all kinds of construction processes. It is a subject that is not always common but more common as a side aspect, while it should be meaningful. One of the purposes of standardisation is to increase the industry's safety. This safety translates to a safer assembly process of the element concerning its situation beforehand. Secondly, at the prefabrication of these elements, safety should be increased by having an optimal production process.

Hutterelement: having a standard assemblage process and production in a conditioned environment increases safety.

The following section identifies the situation before the standardisation of the Hutterelement. It is essential to indicate why the contractor created this Hutterelement. That focuses on a hand-made wooden construction against the concerning wall behind the toilet.

Technical application:

This wooden construction, achterhout, is applied for fixing the toilet to the wall. Moreover, the contractor installs the pipes of the toilet. This fixation of the toilets and the pipes occurs by wood, but not via a specific description. Therefore, the contractor executes this construction of wood in the metal stud wall by the views of the woodworker.

Construction phases:

The following steps are the main steps in constructing the wood to fix the toilet to the wall. Important to state is that the construction occurs by noticing the situation and assembling the wood at the location based on the perspectives of the woodworker.

1. First the wall
   This step involves the construction of the metal stud wall in the toilet room. Where the metal stud frame has assembled some distance from the constructive wall behind fixated to the floor and ceiling, this metal stud wall consists of a metal frame.

2. The wooden construction
   After the fixation of the metal stud wall, the backwood, achterhout, is constructed to the metal frame. This construction of this backwood occurs based on the woodworker's knowledge and insight.

3. Fixation of pipes
   After the fixation of the wood, the contractor installs the pipes. The pipes are the cold and water pipes for the sink and the disposal of the toilet. The construction of these pipes is performed based on the insight of the plumber of the project. That takes time to make and create. Because the height of the pipes should fit, and that is a critical aspect in fixating the pipes.

This construction process that occurs on-site leads to some quality consequences. Because the technical solution is applied each time based on the insights of the woodworker and other stakeholders, the following effects occur. First, the woodworker saw the metal stud wall's profiles because the worker had to fixate the wood. The quality of the profiles decreases, and the consequences of structural requirements are not known. Furthermore, an extra fixation is sometimes made against the wall behind, while the metal stud wall is placed as a retaining wall to detach these. That leads to more acoustical transmission, while the metal stud wall was there to overcome this issue. Finally, this fixation with specific wood is hard to tune with other installations for the toilet and bathroom. For instance, toilets, and washing sink, while contractors apply these installations in each building. The following paragraphs describe the consequences of using specific solutions for each application.

Quality guarantees. The quality guarantee with these solutions based on backwood cannot be applied. The guarantee of the solution is not known because only the worker knows how they executed it because there is no standard. By constructing a different solution for each application, the quality is hard to guarantee. Therefore, by searching for a standard solution, the rate will increase.

Costs. This backwood solution will be more costly than a standard solution. The contractor sees these costs in the material costs and the time to construct these solutions. The construction costs are relatively high because the creation of the solution does take some time, more than when the solution is a standard.

Engineering costs. The current solution with backwood is not engineered during the design and engineering processes because stakeholders do not define that in the plan of requirements. Therefore, the woodworker and plumber create a solution.

Modelling costs. During the development of the new element, there will be more costs of modelling the solution during the engineering phase. While the current solution, with wood, does not have any modelling costs. However, the modelling of the standard element will not take long because the component is a family in Revit.

Logistical costs. The logistical costs will decrease because only one transport has to occur with one element, and the construction site will be more uncluttered. While with the current application, the contractor delivers the wood and other needed materials to the construction site.

Construction costs. The assemblage costs will be lower for a standard element with a common assemblage method. At the same time, the cost of the wooden framework that the worker made for all situations takes more time because there are more specific time-consuming tasks than when a standard element is applied.

Maintenance costs. The quality of the wooden framework solution is lower than a standard solution because the contractor does not measure the quality of these rigid solutions. The contractor constructs these frameworks at the site, and therefore the guarantee and quality are unknown, whereby the costs for maintenance will probably be higher.

5.2 Define standard conditions for developing the element

The step of the proposed design process focuses on defining the design conditions. The contractor needs multiple characteristics as input for developing elements in this proposed design process.

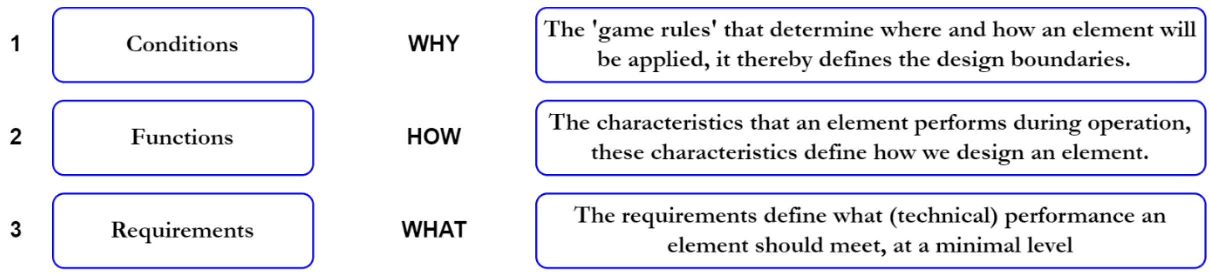

Figure 42 - overview functions, conditions and requirements

Figure 42 gives an overview of the relevant assumptions defined before the design can start. Because the study indicates three types of assumptions, it is critical to state how they relate to each other and give the definitions. The following section elaborates more on applying the standard conditions concerning the Hutter element.

First, the action is more elaborated. This step focuses on defining the standard conditions of the concerning element. That implies that the defined context limits the applicability of the component. The condition should clarify how the contractor can apply that element. Then, the focus is more on the component's dimensions concerning the context where the component will be applied.

This study identifies a scope by defining the context and the type of buildings where the element will be applied. The range is critical to know how and why to use the element. Furthermore, this defined context helps scope the design process and is therefore needed to understand the dimensions of the element. The context determines the type of building where the element will be applied.

The study uses the following approach for the definition of the design conditions. Based on the information available on the design of the Hutter element, the following conditions are defined and elaborated.

Where apply:

1. **<u>Where in the building:</u> Element should be applicable in toilet rooms, focus on rooms with sanitary services;**

   This first condition elaborates where the element should be applied, which is the location in the building. In other words, this condition implies defining the context of the building where it will be fixated and assembled.

2. **<u>Potential function:</u> The element should be applicable for the fixation of the toilet and washing table;**

   This second condition focuses on which products apply to the element. Thus, this condition should define the context of the products/components related to the component.

3. **<u>Building types:</u> In 80% of all utility building projects;**

   Schools, offices, hospitals, nursing homes

   The third condition focuses on the minimal amount of projects of the contractor. The condition should apply to the type of industry, which is, in this case, the utility building industry.

How apply:

4. **Dimensions:**
   - 4.1. **<u>Height</u>: flexible**
   - 4.2. **<u>Width</u>: maximum of 900mm**
   - 4.3. **<u>Length:</u> -**
   - 4.4. **<u>Depth:</u> values of metal stud walls**
   - 4.5. **<u>Grid:</u>**

This condition focuses on the sizes of the element. It is essential to indicate the main characteristics of the dimensions. That helps to know how the element can fit in the context defined in the first three conditions. The study bases these dimensions on information known by research on other utility building projects as a reference. However, these dimensions indicate how the contractor designs the element, while the development team should create these parameters during the design process. Therefore, these dimensions are an indication and an assumption in the design process.

The height is flexible because the contractor wants to apply the Hutterelement in multiple types of buildings. At the same time, the element's width is according to the known width sizes of existing toilets.

5. **Technical application:**
   - 5.1. **in metal stud walls**

This condition focuses on the specific technical context where the element should be applied. Thus, the technical context wherein the contractor applies the component. This context can differ because the construction industry knows many types of construction methods. It is essential to indicate the technical construction context to eliminate other construction contexts.

According to the Hutter element, the context is indoor walls wherein this element will be applied. There are multiple indoor walls, and one is specifically more involved in sanitary rooms, which is metal stud walls. This construction method is the context wherein the Hutter element should fit.

5.3 Define functions of the element

Identifying the main functions of the element is part of the primary design process. Therefore, the essential functions of this element are part of the conceptualisation. The study elaborates on these functions as the main characteristics this element should fulfil. As stated in Figure 43, the functions indicate what the component should perform for the end-user, i.e., the client. These functions are the primary purpose of applying the element in the building, and the contractor should meet these because these aspects underline the critical line of customer value. These aspects differ per element; the following functions are defined and elaborated for the Hutter element. Because the contractor applies the component in toilets, the component does not have any isolation functions.

Fire Safety: this function is one of the primary essential purposes of the element. By applying this element as a retaining wall (voorzetwand) in toilets, the element is part of the wall behind it and, therefore, part of the fire safety requirements.

Fixation of the toilet to wall: the essential function of the element is to fixate the toilet, urinoir or washing table to the wall. This fixation function means that there should be an interface between the wall and the toilet. Furthermore, the components should handle the forces on the toilet and retaining wall element itself. This fixation includes structuring the disposal and supplying water pipes for the toilet. The contractor applies the pipes structurally by performing a standard element, which is needed to enhance quality and assemblage time.

Acoustical reduction: this retaining wall influences the acoustics of the toilet because toilets generate some moments of sound that the contractor should eliminate as much as possible. Therefore, a significant function of this retaining toilet wall element is an acoustical disconnection to reduce sound transmission.

Water resistance: the element should be water-resistant because the contractor applies it in toilet rooms, which requires water resistance.

Impact resistance: It should be impact resistant because it is a wall. That implies the wall should handle forces that affect it. These forces could be from people using the toilet or other related forces.

Esthetical freedom: the element includes the last layer of the esthetical finish. Therefore, it has an esthetical function. The component should be finished according to the needs and requirements of the client and architect.

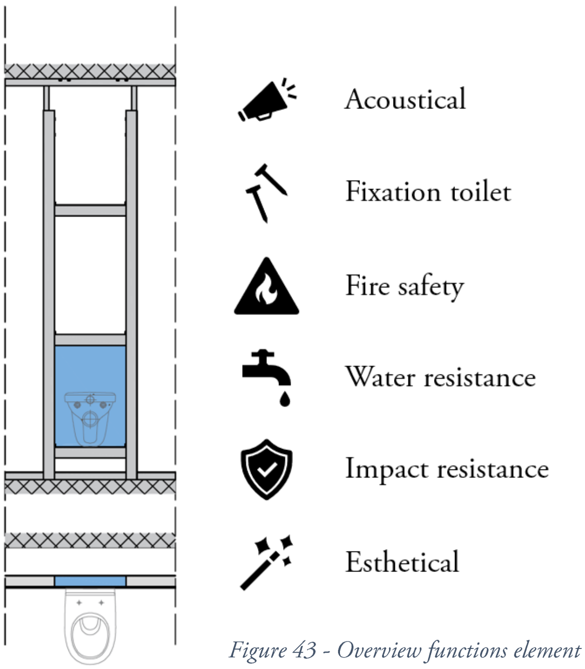

Figure 43 - Overview functions element

5.4 Indicate all relevant design requirements of the element

Step four of the design process involves the indication of the design requirements. Therefore, this study creates an overview of the requirements divided into BAM requirements, law and regulations, and client requirements. Requirements are essential in the design of the projects as standard elements. Besides the conditions and functions, the requirements are critical as assumptions for creating the element. This section specifies and elaborates on the requirements. The study elaborates on these requirements in Appendix 3, in the Information Delivery Manual, on pages 35 and 36.

The design team should test the design choices to the following requirements during the design and development. Figure 44 gives an overview of the concerned requirements.

REQUIREMENTS		
GENERIC	LAW & REGULATIONS	CLIENT
- production process	- floor area	- height
- flow	- floor area deviation	- use
- transport trucks	- minimal height	- safety
- transport seizes	- fire safety exposure	- costs
- assemblage	- fire safety insolation	- quality
- operation	- load capacity urinoirs	- future usable
- modular design	- load capacity toilet	- sustainability
- parametric design	- load capacity sink	- replacability
- standard		- color - appearance
- quality		- dimensions
- financial efficiency		- maintenance
- guarantee		- lifespan
- sustainability		
- circularity		
- materialisation reused		
- materialisation reducing emissions		

Figure 5 - Overview of requirements

5.5 Indicate different technical solutions of the element

According to the available information on the development of the Hutterelement, the team indicated the following technical concepts. These concepts show another kind of construction solution of the element.

Wooden framework

The team-based this framework on wooden beams of a standard size. Furthermore, the team based these sizes on the depth of the water reservoir component of the supplier. The framework is prefabricated to decrease assemblage and transportation costs and increase productivity. By prefabrication, safety at production and construction sites increases and quality increases. A standard assemblage method enables productivity, and therefore this framework is prefabricated and standardised. The following Figure 45 indicates the set-up of the framework and how it relates to the context to where the contractor it can apply.

There are two significant issues with the application of this framework in wood. The first issue is that the element's height is not easy to design flexibly with standardisation and prefabrication. The design team needs to design the height flexibly because the contractor should apply the component in multiple building types where the height is different between a predefined interval. The second challenge is that the element should apply to a metal stud wall applied in the toilet rooms of utility buildings. That influences how to develop and create the framework in wood. An overview of the element is in Figure 46.

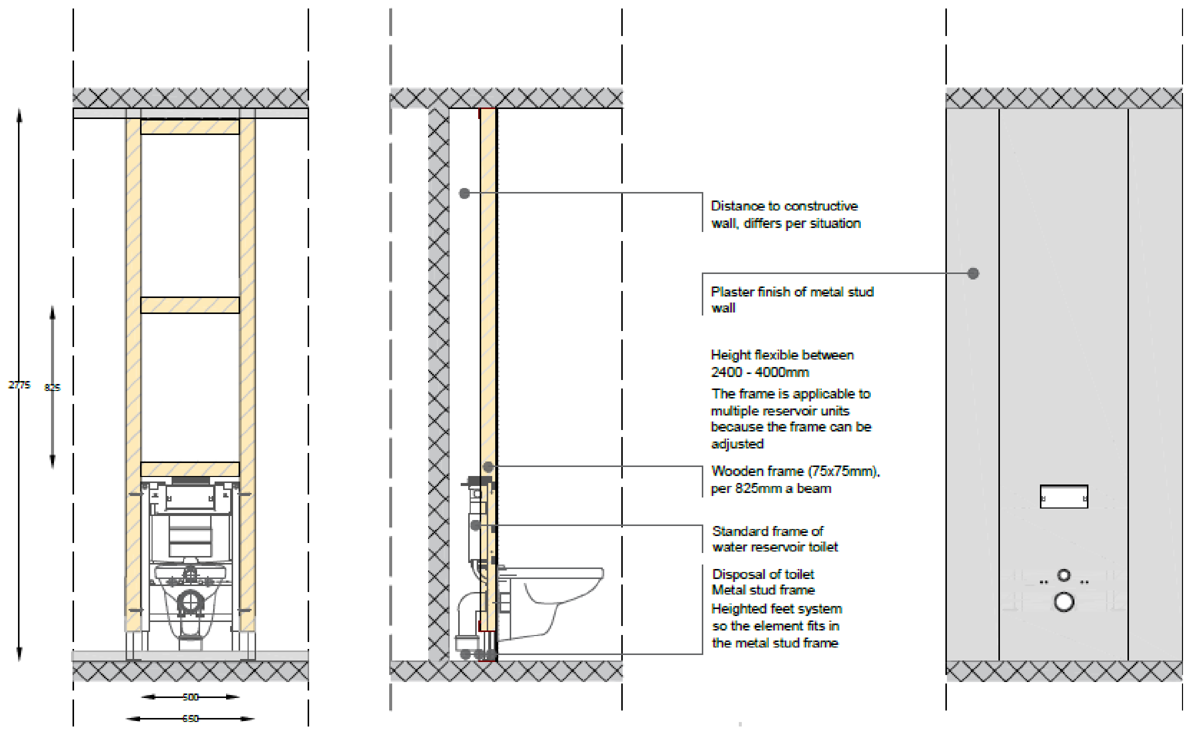

Figure 46 - SO drawings wooden framework concept

The design team designed this wooden framework concept according to the proposed design process. It is a conceptual design of the wooden concept and meets the generic and client requirements and laws and regulations. First of all, the concept includes parametric, modular design and standardisation. Then, the team can meet the production-related requirements because the idea is easy to produce, transport, assemble and maintain. Furthermore, by designing the concept with wood, the focus is on sustainability and circularity. The quality will be excellent and easy to guarantee. In Appendix 5, the study added a drawing of the concept.

Metal framework

The design team bases this concept on metal profiles, the same as the applied metal stud wall. Therefore, this concept fits directly in the metal stud wall and has multiple advantages instead of the wooden framework. The top of the element fixates according to the height of the floor. That is easy to change according to the flexible height system that the concept includes. The element fits directly in the U-profiles of the metal stud wall. Furthermore, the water reservoir component of the partner integrates easily into the metal frame because the reservoir component is most often applied in metal. Figure 46 gives an overview of the metal concept.

By applying this concept, there arise some challenges. First, metal is not a sustainable friendly material; many emissions occur with its production. However, because it has well structural characteristics, the amount of needed material is low.

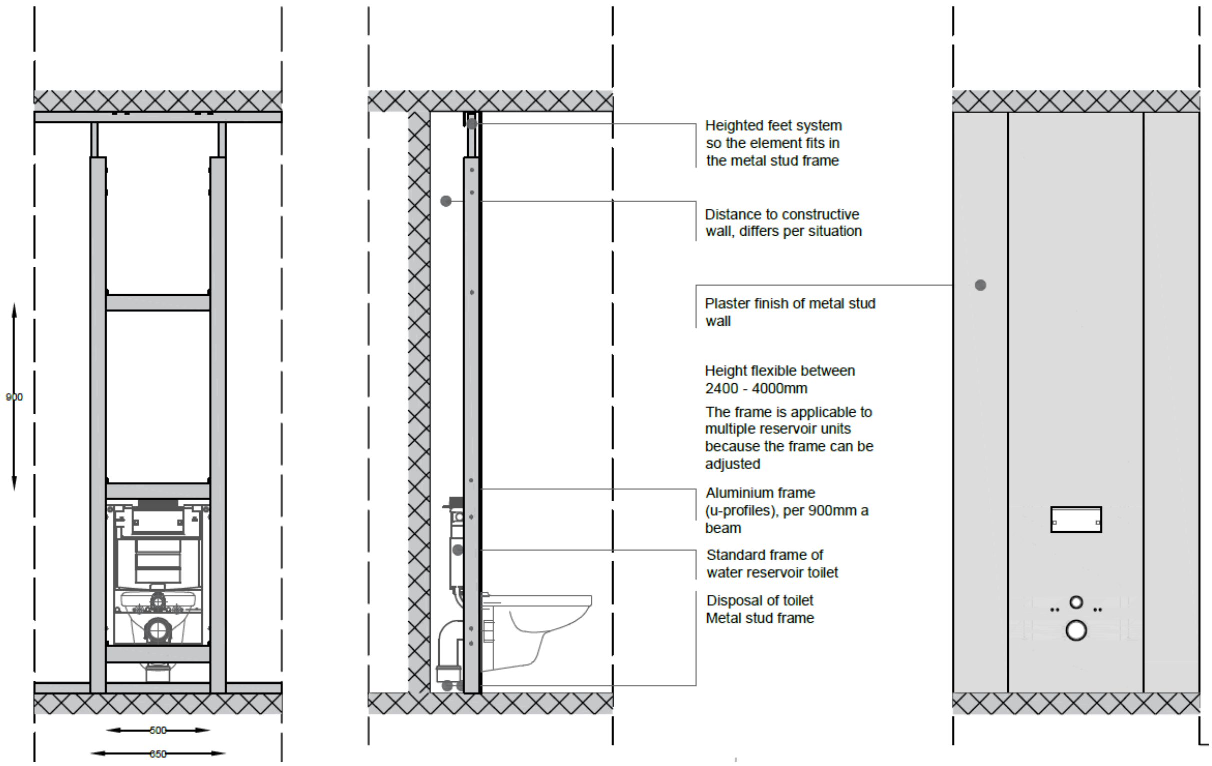

Figure 46 - SO drawings metal framework concept

This concept meets many requirements very well; first of all, it is easy to assemble. Because the concept fits directly in the metal stud wall, and it is a lightweight concept. That has a positive influence on the transport, production and assemblage. The concept also applies the design concepts of parametric, modular design and standardisation. The concept is parametrically owing to the flexible height system and modular because the element is easy to assemble and disassemble.

Additionally, the concept is according to the design conditions applied. Furthermore, the metal profiles enhance the circularity of the element because the contractor can use the profiles in other structures and places. Applying less material improves the sustainability of the component. The SO drawing in Appendix 6 gives more indication of these aspects.

5.6 Select the appropriate concept to design and develop

The proposed process applies the trade-off matrix at the moment when the design team chooses one of the technical solutions to design into a parametrically, modular and standard element. These technological solutions are different technical applications of the currently available element. In the case of the Hutter element, the team identified the following technical solutions and traded them off.

- Concept 1 - Wooden framework
- Concept 2 – Metal framework

The partner and the development team identified these two technical solutions or applications of the Hutterelement. Based on these two identified technical applications, the study chooses element one to design and develop into a standard component for the utility building industry. The study executes this trade-off in the following matrix, which the research bases on the element's defined requirements. The requirements are translated into this matrix and interpreted per technical solution, i.e., concept. These BAM requirements examine the concepts, and the specific regulations and client requirements do not specifically influence the trade-off.

In Figure 47, the study gives an overview of the trade-off matrix. The research added it in Appendix 7 as a reference. The design team should use this trade-off matrix in each design process of elements for utility buildings. Then, the team needs to change the requirements according to the related and defined requirements.

For the conceptualisation of the Hutterelement, the research trades the two concepts in this matrix. This trade-off concludes that the metal framework is the best concept. This concept offers the highest productivity through an easy production and assemblage process. Furthermore, the concept has more quality than the wooden concept because it fits better in the metal stud wall and has a precise, more durable, flexible height system. The metal framework scores on sustainability some lower because of the metal material concerning wood, but overall the flexibility, quality and efficiency score better.

Project : <Hutterelement>

Trade-Off-Matrix		SBS Onderdeel :											
Object ID : Document nummer : Versie / Datum A / 2017-02-06 Opgesteld HRE Bijlagen geen	Weegfactor	Concept 1	Score	Waardering	Concept 2	Score	Waardering	Concept 3	Score	Waardering	Concept 4	Score	Waardering
Duurzaamheid													
EPC score													
GPR score: Energie													
GPR score: Milieu													
Circulariteit													
Materialisatie													
Productie													
Productie proces													
Flow													
Transport trucks													
Transport formaat													
Assemblage													
Exploitatie													
Ontwerp													
Modulariteit													
Standaardisatie													
Parametrisch													
Efficiency													
Kwaliteit													
Kosten													
Risico's													
Vergunning gemeenten/provincie													
Brandstofprijs													
Afweging keuze :													
Score		0			0			0			0		
Oordeel													
Definitieve variant :					WKO open - Collectief								
Opmerkingen													

Legenda	Score / risico	
	(++) voldoet / gunstig / geen	2
	(+) voldoet mits / klein	1
	(o) neutraal / niet van toepassing	0
	(-) voldoet mits / ongunstig / matig	-1
	(--) voldoet niet / slecht / groot	-2

Figure 47 - Trade-off matrix Hutter element concepts

5.7 Steps 1.7 – 1.8 – 1.9 - Parametrizing

In conceptualising the Hutter element, the indication and definition of relevant design parameters is essential because that includes the parametric design in the concept. With these design parameters, it will become possible to design flexible, which implies that the design of the element can change according to the value possibilities of the design parameters. It is essential to state that not all components, products, parts and solutions of the element will be designed based on parameters. The team will design some features parametrically when that feature should be flexible, as an answer to a requirement, an answer to the defined conditions, or a reaction to possible technological solutions. Other features will be applied in one standard, i.e., one solution, whereby the standardisation increases. Thus, there is a ratio of flexibility and uniformity in the design of an element. According to the interviews, this ratio is about 80-20, which implies that 80% is standard and 20% of the team can design parametrically. The study bases this ratio on the interviews. Figure 48 gives an overview of the related parameters to the Hutterelement.

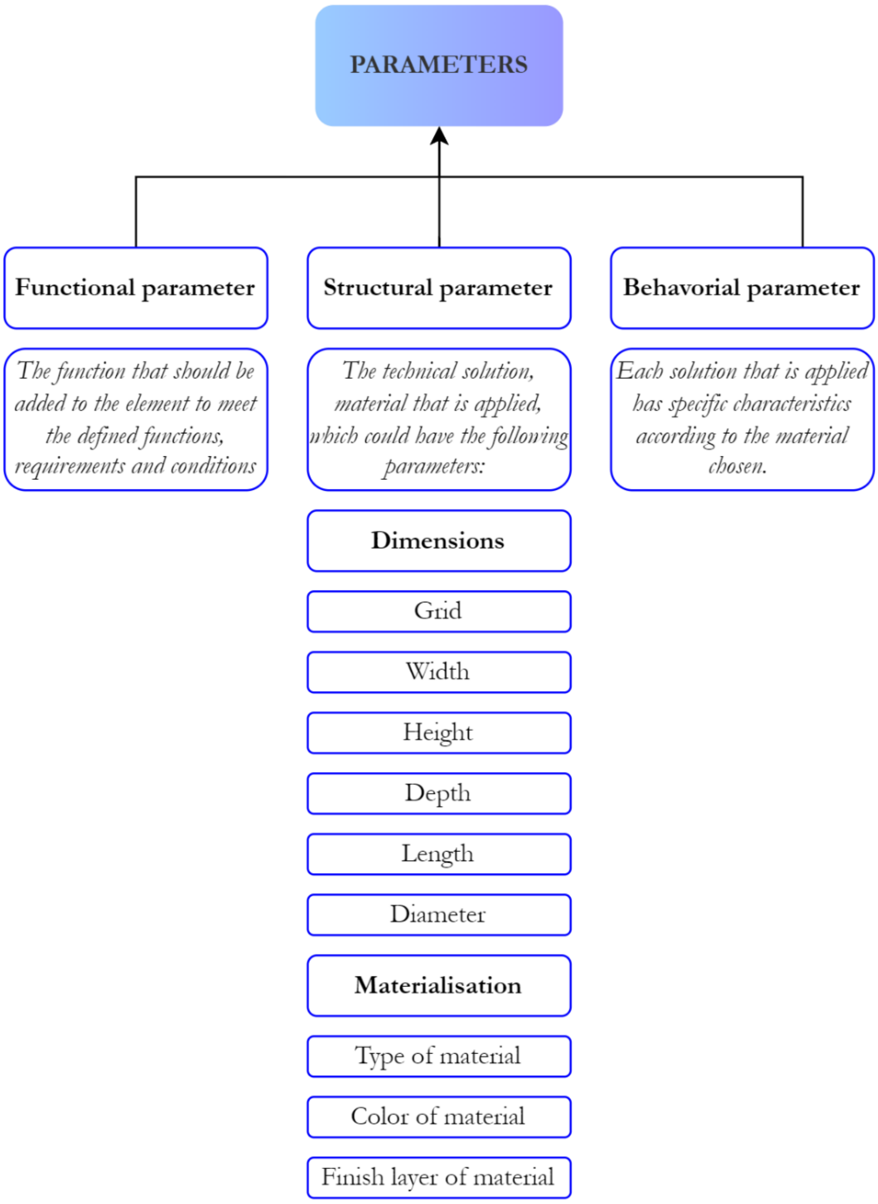

Figure 48 - Overview parameters Hutterelement

The following section describes the parameters identified as element parts that the team should design flexibly. This section includes steps seven, eight, and nine of the overall design process. The section combines the steps to shorten the general elaboration because this chapter only conceptualises the Hutterelement. When the contractor designs an element in actual conditions, the execution of these steps should be more elaborately. Figure 49 gives an overview of the relevant parameters.

Furthermore, another assumption is that this research uses the knowledge available of the design process Hutterelement. The research did not conduct more significant research on multiple reference projects. That research towards many constructed projects within the design conditions gives insights into how to define and design the concerning parameters.

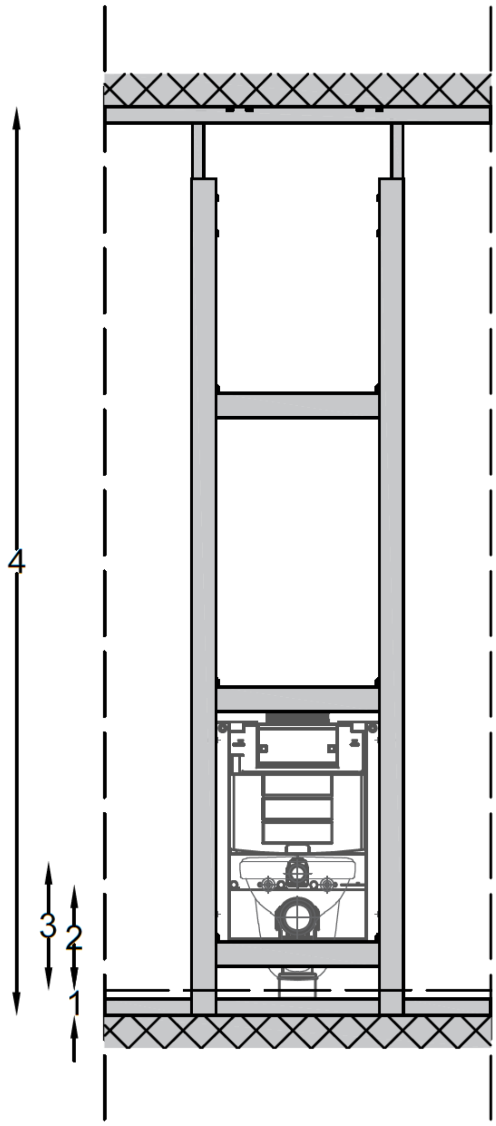

Figure 49 - Overview parameters of element

Height of floor

Step 1.7 – What is the specific definition of the parameter, and what is the context? The floor height of utility buildings differs per type of building and design. The design conditions state that the element should be applicable in schools, offices, and hospitals. These buildings have different heights. By indicating as many related utility building projects as possible, it is possible to show how the parameter should be applied. This parameter indicates the height from concrete flooring to concrete ceiling. The element fixates against the concrete floorings of the project.

Step 1.8 – How apply the parameter: multiple standard variations or flexibility between intervals? According to the element's available knowledge, the height should be the best designed and flexible between a determined interval. By creating the element's height flexible, the contractor can apply the elements in multiple variations of buildings. Because there are many variations in height between utility building projects, it is better to design the height flexible.

Step 1.9 – What should be the value of the variations or intervals defined in step 1.8? The interval of the flexible height should be between 2400mm and 4000mm. According to the available information, these intervals are according to the constructed utility buildings.

Furthermore, Table 15 on the next page generates an overview of the involved exchange requirements involved in the design of this Hutterelement. This format incorporates an overview of the involved relevant parameters for designing the element in Revit. Moreover, it is part of the IDM and, therefore, necessary to create because it generates an overview of the related design parameters and how the design team should map the exchange requirements. This step is essential in creating a thorough overview of the element.

Exchange Requirement for Hutterelement

Element	Property Concept	Property Name	Definition	Example and explanation Test using a rule in (pseudo code)	Existence[1]	Value Type[2]	Cardinality[3]	Unit[4]	IFC Mapping
Hutterelement									
	General element requirements								
		Identification	A short name or element number is used for reference.		R	String	n/a	n/a	ifcElement.Name
		Name	A name that describes this element is used for reference.		O	String	n/a	n/a	ifcElement.LongName
		Description	General information of the purpose of the element.		O	String	n/a	n/a	ifcElement.Description
		Author contact information	General information of the author of the element.		O	String	n/a	n/a	ifcOwnerHistory.LongName
	Element classification								
		Element classification	The element can be classified using a reference library or any national standard for project-specific classification.		R	String	n/a	n/a	
	Frame requirements								
		Identification	A short name or element number used for reference		R	String	n/a	n/a	ifcFrame.Description
		Industry classification	A specific classification of the frame by industry standards.		R	String	n/a	n/a	ifcClassificationReference.ItemReference
		Shape profiles	The shape of the profiles used for the frame		R	String	n/a	n/a	ifcQuantityShape.Name='ShapeProfiles"
		Frame height	The height of the frame		R	Real	n/a	mm	ifcQuantityHeight.Name='HeightFrame"
		Frame thickness	The thickness of the frame		R	Real	n/a	mm	ifcQuantityThickness.Name="ThicknessFrame"
		Frame width	The width of the frame		R	Real	n/a	mm	ifcQuantityWidth.Name="WidthFrame"
		Frame weight	The total weight of the frame		O	Real	n/a	kg	ifcQuantityWeight.Name="WeightFrame"
		Frame material	The material of the frame		O	Real	n/a	n/a	ifcQuantityMaterial.Name="MaterialFrame"
	Toilet reservoir component requirements								
		Identification	A short name or element number used for reference		R	String	n/a	n/a	ifcReservoir.Description
		Industry classification	A specific classification of the reservoir by industry standards.		R	String	n/a	n/a	ifcClassificationReference.ItemReference
		Reservoir Height	The height of the reservoir component		R	Real	n/a	mm	ifcQuantityHeight.Name="HeightReservoir"
		Reservoir Length	The length of the reservoir component		R	Real	n/a	mm	ifcQuantityLenght.Name="LenghtReservoir"
		Reservoir Width	The width of the reservoir component		R	Real	n/a	mm	ifcQuantityWidth.Name="WidthReservoir"
	Toilet requirements								
		Identification	A short name or element number used for reference		R	String	n/a	n/a	ifcToilet.Description
		Industry classification	A specific classification of the toilet by industry standards.		R	String	n/a	n/a	ifcClassificationReference.ItemReference
		Type toilet	Type of toilet applied in the element		R	String	n/a	n/a	ifcToiletType
		Fixation height	The fixation height of the toilet		R	Real	n/a	mm	ifcQuantityFixation.Name="HeightFixation"

Table 15 – Exchange requirements Hutterelement

[1] Either one of M – Mandatory | O – Optional | R – Recommended | N – Shall not be used

[2] Either one of Boolean, Integer, Real, String, Relation, Object type etc.

[3] Where applicable: number of items per property such as <= 2 (less or equal to two items per property)

[4] Where applicable: (e.g. m, m2, m3 etc.)

5.8 Conditions for applying elements

This paragraph describes the conditions for applying the Hutter element in a utility building element shortly. Thus, the contractor needs to meet the following conditions; otherwise, they cannot use the element. This research bases the points on the defined standard design conditions.

Appropriate to apply:

- A minimum of ''(xx)'' elements should be applied per project.

Where applicable:

- The focus is on rooms ''*with sanitary services.*''
- Useful in ''*80%*'' of utility building projects

Where not applicable:

- **Type of buildings:** ''*residential*''
- **Technical:** ''*kalkzandsteenwanden, betonwanden*''

How apply:

Dimensions:

- Height: ''*flexible between 2400mm – 4000mm*''
- Width: ''*standard: 900 mm*''
- Length: '' ''
- Depth: ''*three variations in: 50mm, 60mm, 70mm*''

Application:

- ''*In metal stud wall*''

5.9 Implementation

An essential aspect of the conceptualisation is how it relates to the further implementation of the process within the company of BAM Bouw en Techniek and in other larger contractors. This section focuses on the implementation of the proposed process and defines recommendations based on the conceptualisation.

Process implementation

The contractor can use the process in the organisation, however, there are some aspects to take into account with the implementation and performance of the process. First of all, it is essential to understand the implications of applying the process. Thus, to know what kind of the impact it does have on the organisation because the process needs a concept organisation, a design team and management that takes the process seriously. The following actions should the contractor perform starting with the performance of the process:

1. Create a concept business organisation: this organisation stands alone from the contractor and develops the elements to standard, parametric and modular. Furthermore, this organisation sells the elements to the main contractor and other companies in the industry. It is essential to create an organisation that does not have many connections with the main contractor because there are the main barriers found.
2. Create a development team: a team that designs and develops the elements within the above-described organisation.
3. It is essential to do a thorough research of many utility projects BAM executed in the last years, these projects identify how the design team can standardize the chosen elements. This research is thus a basis for the standardisation in the company, and the design team should document the research well.
4. The construction industry tends to focus on the technical and financial aspects of construction, however, this process concludes that the soft aspects such as mindset, organisation and collaboration are essential for performing standardisation. Therefore, with the use of this process, it is crucial to work together and collaborate with the identified stakeholders.

Standardisation

The further implementation of standardisation in the company of BAM Bouw en Techniek should take the following aspects into account. Process standardisation is the first aspect to standardise, however, more aspects need to be studied and implemented carefully.

1. The company should make clear how it wants to apply standardisation, where this research applies it in process form. This aspect implies identifying in which forms the company wants to apply standardisation.
2. Create a strategy, vision and mission around standardisation: employees, stakeholders and the whole organisation of the contractor should take standardisation seriously, therefore the contractor needs a structured vision of the implementation and the goals of standardisation.

Identified challenges

This research identified multiple significant challenges to overcome, these should be tackled carefully because they challenge the current practices of the contractor. The three identified challenges are more elaborated on below:

1. Demonstrating solutions: developing more and more standard elements, with first the focus on installations and then the focus on building elements such as construction, indoor walls, and toilets.
2. Culture and mindset: this is probably the most significant challenge. Therefore, this study recommends doing further research into this subject and how this relates to standardisation in the construction industry.
3. Organisation: for this aspect, this study recommends doing further thoroughly research into how the organisation should look with standardisation. Furthermore, some projects will be still very specific and other projects more standard. It would be good to identify for each project what kind of standardisation there can be applied, is it a one-off or a standard? This influences how the organisation should handle a project and how the contractor should apply standardisation.

5.10 Conclusion

This conclusion focuses on the development of the Hutterelement according to the proposed design process, a conceptualisation to validate and discuss the developed design process. This chapter follows the twelve steps according to the proposed design process to do this conceptualisation. These twelve steps give a structured overview of the essential tasks of the process.

By conceptualising these twelve steps, they validate the proposed process. Furthermore, the validation assures the steps perform as they should and according to the elaboration in the IDM. The Hutterelement performs mostly perfectly according to the proposed process because this chapter uses the first available design information of the element as a reference for the development of the design process. During this conceptualisation, the steps translated the available design information into the twelve steps,

As a result of this conceptualisation, the study updated the BPMN process map. The conceptualisation showed some design process gaps, which resulted in an update. Another crucial aspect is the validation of the process that focused on a panel discussion and the comparison with the distribution rack. The results of the validation are mostly all translated into the process and thesis.

The study executed this conceptualisation in a small range of time. Therefore, the final design of this element could be more elaborated and in-depth. Furthermore, the research and studies on other projects as references for designing the element could be done more thoroughly.

6. Conclusion & Discussion

6.1. Research conclusion and scientific relevance

The study aims to enhance the industrialisation and digitalisation of the utility building industry by performing standardisation, parametric, and modular design. As a result, it enhances the industry's sustainability, productivity, safety, quality, and financial feasibility. This research towards standardising the utility building industry states the following central question.

How can the design process of utility building elements be standardised, and how can that process be implemented?

The literature review results show a relation between parametric design, modular design, and standardisation. This relation offers different perspectives that combine these design concepts in the design of an element, 1) is then in some parameters flexible; 2) by variations or between an interval; 3) and modular by coordinating the interfaces of an element; 4) and standard by designing according to predefined design conditions. The relations arise during the application of the concepts of designing an element.

According to the conducted interviews, questioned project leads and directors involved in the utility building industry, the central challenges the utility building industry faces are 1) the culture of all involved stakeholders; 2) the organisation around standardisation within a contractor; 3) demonstrating the solutions. The interview results concluded that the current culture and mindset of the involved stakeholders are not sufficient to enable and enhance standardisation. Furthermore, contractors need another organisation to facilitate concept development and management. Nowadays, the industry focuses on creating projects, while standardisation requires an organisation that centralises the development of project transcending elements. The third challenge arises in demonstrating solutions that meet the demand and requirements of society and involved stakeholders. Therefore, this research proposes a standardised design process.

Furthermore, the results show that the utility building industry can standardise the design process of the elements according to the main conditions. This proposed process includes the purposes of designing an element parametrically, modularly and standard. Furthermore, this process refutes the barriers and challenges described in the literature review and applies the enablers to meet society's demand by increasing productivity, safety, quality, and financial feasibility. Additionally, the conceptualisation of the Hutter element shows how the contractor should execute the implementation of the process.

This research fills a gap in the scientific study of standardisation focused on the utility building industry. There was no state-of-the-art literature available that combined these design concepts. Furthermore, the proposed process incorporates the studied barriers, benefits, challenges and design concepts and is therefore generalisable for other main contractors. Thus, this research shows that the utility building industry can enhance industrialisation by designing standard, parametric and modular elements.

6.2. Societal Relevance

This study enhances the construction of utility buildings by focusing on standardisation: leading to increased productivity, quality, safety, and financial feasibility. These consequences of applying standardisation have a positive impact on society. Due to these effects, the users of a utility building experience a higher performance of appearance and functionality. Furthermore, society experiences this economically due to increased productivity, and this research enhances the use of design concepts that are in line with community needs.

6.3. Discussion

The research results answered all sub-questions, concluding that the research is according to the study proposal, thus in-line with the expectations. Furthermore, the results are generalisable and usable in the context of the utility building industry. The interviews suggest that the industry has significant challenges, focusing on culture, reorganisation and demonstrating solutions. This study has been unable to verify how the challenges of culture and reorganisation should be tackled and concentrate on the design process of demonstrating the solutions. The proposed design process relates to the literature review and the interviews, where the scientific and practical perspectives are studied and applied. This process is structurally developed into a BPMN process map, investigated in the literature review, and responds to the demand to industrialise the construction industry. This research shows it is possible to take the following steps towards a more industrialised construction industry.

Implications of this research are that it shows that the utility building industry is facing significant challenges in performing industrialisation, that is around reorganisation and the culture and mindset in the industry that influences. That demonstrates that the construction industry should focus on the more soft skills and social innovation that come with more significant, technical transitions. By performing and implementing the results of this research more, the consequences are that Royal BAM Group can focus more on industrialisation. Furthermore, it helps BAM Bouw en Techniek strategise industrialisation according to the Group's strategy.

The reader should bear in mind that this investigation collaborates with Royal BAM Group. However, this collaboration does not negatively influence the generalizability of the results. Conversely, this collaboration resulted in interviews with many experts from the Royal BAM Group. These limitations do not affect this research's significance and scientific value. However, it is essential to know and discuss these.

6.4. Future Research

This research suggests focusing on two significant challenges that arise with the performance and implementation of standardisation in the utility building industry. These challenges emerged from the semi-structured interviews, from mainly internal experts of Royal BAM Group. The interviews state that it is essential to take the involved stakeholders, from architects to engineers, into account with industrialisation. Therefore, this study recommends doing thorough research on stakeholders' societal culture and mindset on how the industry can consider these. Furthermore, the research suggests studying how a contractor organisation should change from project-focused to industrial-focused.

This research underlines the essence of innovating the utility building industry because the future needs a sector that can industrialise construction systems. This research indicates the start of this future.

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8. Appendices

1. Interview guide – NL and EN
2. Interviews minutes (13)
3. Proposed BPMN process map
4. IDM report of tasks and exchange requirements
5. Report design requirements
6. VO drawing wooden concept
7. VO drawing metal concept
8. Trade-off matrix