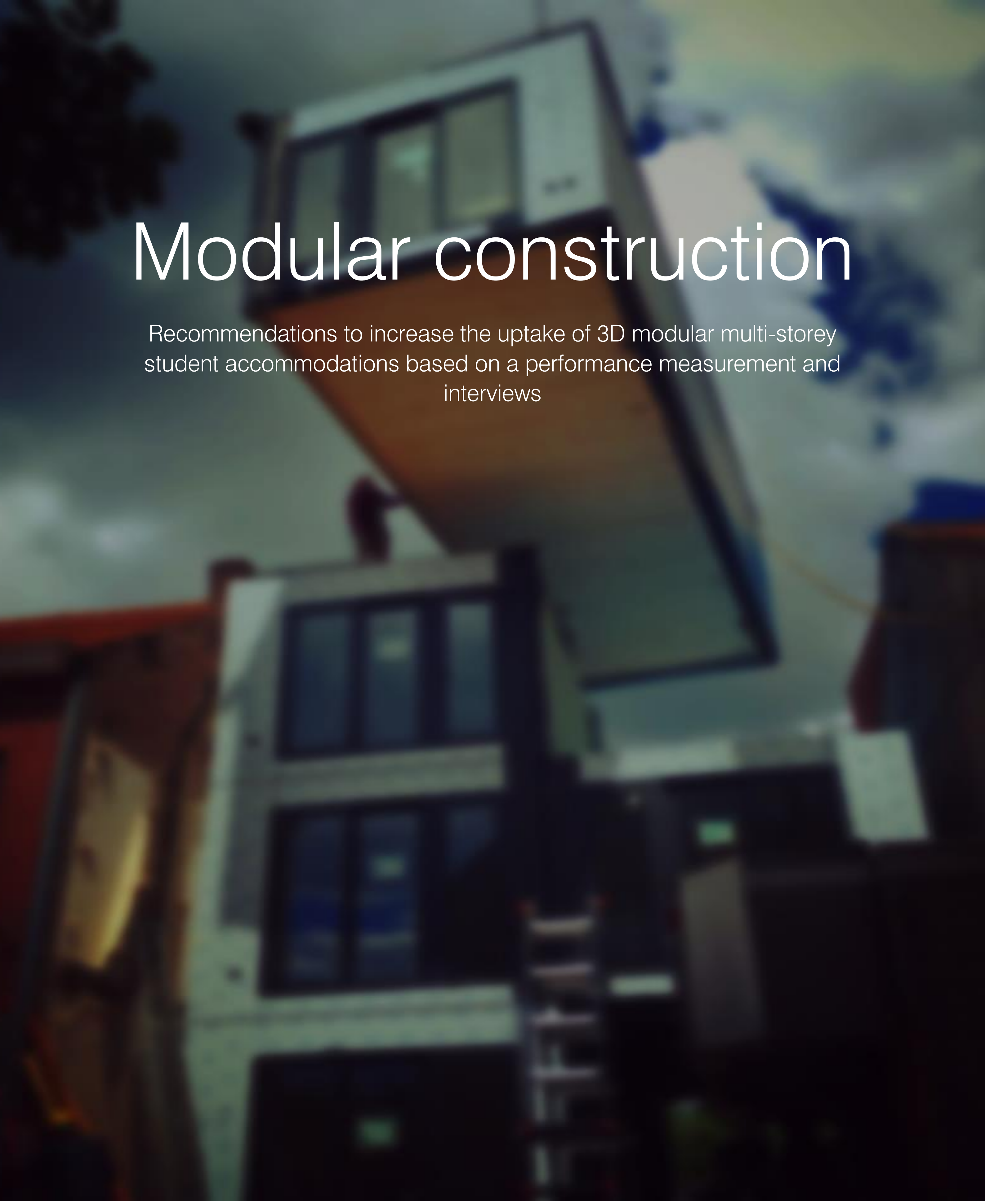

Modular construction

Recommendations to increase the uptake of 3D modular multi-storey student accommodations based on a performance measurement and interviews

P5 Report

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ABSTRACT

The housing market in the Netherlands faces two challenges which are the housing shortage and the climate crisis. Modular construction can help solve these challenges due to the many advantages that modular construction has over traditional construction. The advantages that are most related to solving these challenges are the reduced construction time, reduced waste production, reduced transportation movements and the reusability of modules. On top of these advantages modular construction offers many more advantages over traditional construction such as reduced construction cost, reduced failure cost, increased quality, increased worker safety, reduced disturbance for neighbouring buildings and reduced need for traditional labour. Despite all these advantages, the uptake of modular construction is still quite low, mainly due to three problems. The summary of these problems comes down to that there is a lack of knowledge about how to implement modular construction properly, so that the advantages of modular construction can be realised. Therefore, in this graduation research, recommendations will be given on how modular construction can be implemented better so that modular construction performs well. To do this, the following main question has been used: ***"What is the current performance of 3D modular multistorey student accommodations in the Netherlands and how can this performance be increased?".*** As the research question says, this research will focus on 3D modular construction that is used for multistorey student accommodations in the Netherlands. This research will include theoretical review, a performance measurement of modular buildings and recommendations to improve this measured performance for future modular buildings. The theoretical review forms the basis for this entire research, as it gives knowledge to the state of the art about 3D modular construction. The performance measurement considers the objectives of the entire built environment and the student housing association DUWO. Based on these objectives the performance of three modular student accommodations will be measured. The final product of this research will be to give recommendations about how the measured performance of the modular buildings can be increased. These recommendations are based on interviews with experienced stakeholders, combined with the theoretical review.

Key words: 3D modular construction, performance, advantages, obstructions, student accommodations

PREFACE

This report shows my graduation research in which I research the performance of modular multistorey student accommodations in the Netherlands and give recommendations for improving this performance for future modular buildings. This report is part of the graduation period of the master track Management in the Built Environment of the master Architecture, Urbanism and Building Sciences at the Delft University of Technology.

In September 2021 I started my graduation process, and I chose the topic of modular construction. The reason for choosing this topic was because I got inspired by the Tesla factory. When I was looking at videos of the Tesla factory and how they were trying to increase productivity with the use of a giga press and automation, I thought why isn't this used more in the building sector. In my opinion when efficiency is increased, the cost of buildings can be decreased and more buildings can be produced, which will help reduce the rapidly increasing housing prices and the housing shortage. Furthermore, when less materials have to be used for the construction of buildings, the construction process will have less environmental impact, which is a real issue as well. To achieve this industrialisation of the buildings sector just like the Tesla factory, I found the topic of modular construction. When I started looking into modular construction, I discovered the SUM team, which has found a solution to make renovation of tenant flats feasible by renovating them using modular construction. This was so interesting to me that I joined them as construction coordinator for their prototype, to experience the advantages and disadvantages of modular construction in practice and to use this knowledge for my research to modular construction.

This research would not have been possible without the people that helped guide me through this process and helped me gather the needed information. Therefore, I first would like to thank my mentors at the TU Delft, Peter de Jong and Herman vande Putte. They were involved from the beginning of this research and helped me shape the output of this research. They were always available if I got stuck or if I just needed to discuss some topic, which made the whole graduation process a lot more enjoyable for me. Furthermore, I would like to thank Mariët Jaarsma who was my graduation mentor from DUWO. She was always ready for me if I had questions and we had regular meetings to discuss the progress. She also helped me a lot with gathering information about the analysed buildings and she involved me in a modular project which she was starting, which I really enjoyed. Within DUWO there are a lot of people which I asked for information or that I did an interview with. I would like to thank everyone that helped me in any way to reach the end of this graduation thesis, it would not have been possible without all your valuable input. Lastly, I would like to thank all the professional stakeholders that were willing to spend their time to give me information through the interviews that were done.

I hope you enjoy reading this graduation research and that the findings are useful!

Kevin Vader

Delft, June 2022

EXECUTIVE SUMMARY

Currently the housing market in the Netherlands faces two major challenges. The first challenge is to build one million extra homes before 2030, to facilitate the population growth that is caused by immigrants, refugees and population increase through birth (CBS, 2020). The second challenge is the goal of the EU to transition to a climate-neutral society before 2050 (European Union, 2020). To achieve this goal, all sectors need to make changes including the building sector. Modular construction can help with these challenges, because of the efficiency increase that modular construction can offer over traditional construction. Because of this efficiency increase, among others Stichting Eigen Huis, ABN Amro and the minister of housing, see modular construction as a solution for the current affordable housing shortage in the Netherlands (Eigenhuis) (de Jonge, 2022) (ABN Amro, 2019). Modular construction can also help with achieving the goal of the Netherlands to become a climate neutral society, because modular construction offers many sustainability benefits (Remkes, 2020). Examples of these benefits are reduced waste production, reduced transportation movements and the reusability of modules.

Despite the many advantages of modular construction, the building sector still heavily relies on traditional construction methods. This means that the advantages that modular construction can provide are not utilized. The main reason why modular construction is not used more is because there is a lack of knowledge about how to implement modular construction properly. This lack of knowledge can be divided in three problems which are:

1. There is a lot of confusion about the term modular construction. Modular construction is often confused with prefabrication, but prefabrication misses the element of standardisation and therefore it has less advantages.
2. Many stakeholders who are involved in the construction process do not understand the advantages and obstructions of modular construction very well. This results in decisions about the use of modular construction being made based on anecdotal evidence rather than rigorous data.
3. These stakeholders are also not sure yet how to implement modular construction in their routine and therefore, for the most part, are currently reinventing the wheel of how to implement modular construction for every project.

The aim of this research is to contribute to increase the adoption of modular construction by addressing the above-mentioned problems. This is done by first defining the definition of modular construction through literature research. After that the advantages and obstructions have been documented, which come from literature, case studies, and interviews. This will be followed by a performance measurement of modular buildings that is used to identify building elements of which the performance could and should be increased. The modular buildings of which the performance has been measured come from the student housing association DUWO, who also served as the case for which this research has been done. Lastly, recommendations are given to increase the performance of modular construction, which will give knowledge to the project initiators on how to implement modular construction. To do this research, some scope limitations have been set to give focus to this research and to make it manageable in the designated time frame. Therefore, this research will specifically focus on 3D modular construction for multi storey student accommodations in the Netherlands. To execute this research the following main question is used:

"What is the current performance of 3D modular multistorey student accommodations in the Netherlands and how can this performance be increased?"

To answer this main question, four sub-questions have been used which are the following:

1. What is modular construction?

2. What are the advantages and obstructions of modular construction?
3. To what extent can modular construction currently satisfy the expectations of student housing associations in the Netherlands?
4. How can the performance of modular construction for student accommodations in the Netherlands be increased?

The first step was to answer the first sub-question. This is very important to understand this graduation research, because in literature and in practice there are many different definitions of modular construction. Often the standardisation aspect of modular construction is forgotten in definitions that can be found in literature and in practice, but this standardisation is key to realise the advantages of modular construction. Therefore, the definition that is used in this research is: “modular construction involves producing standardized modules of a structure in an off-site factory, after which they are assembled on-site”. Based on this definition there are still many different types of modular construction, but this research focused only on one type of modular construction. These types range from 1D to 3D, with 1D being the lowest level and 3D the highest, meaning that more work is already done in the factory. In this research the focus has been on 3D modular construction because construction speed wise this is the most efficient form of modular construction. Standardisation is very important for the advantages of modular construction, because through repetition a more efficient working process can be realised. Therefore, standardisation should be implemented well beyond individual large projects so that industrialisation of the building sector becomes possible.

After the definition of modular construction is clear, this definition can be used for the rest of this research. The next step was to investigate why modular construction should be used more and what is still hindering the uptake of modular construction by answering the second sub-question. To answer this sub-question, information from literature research and information from interviews was used. Through this research has been found that 3D modular construction has many advantages over traditional construction from the perspective of the project initiator. These advantages are: decreased construction time, possibility of disassembly, reduced waste production, reduced transportation movements, reduced construction cost, reduced need for traditional trade labour, reduced failure cost, increased building quality, increased safety and lastly decreased disturbance for surrounding buildings. Besides these advantages there are also quite some obstructions for the use of modular construction. The building sector can be divided in three groups when it comes to obstructions. These three groups are buyers (developer, client, investor), suppliers (architect, modular manufacturer, contractor), and government. Because the focus of this research is on the buyers only these obstructions will be discussed here, but in this report also shortly will be looked at the obstructions for suppliers and government. The buyers experience the organisational structure of a company to be an obstruction for the implementation of modular construction, because of the separation in different branches. Furthermore, an obstruction is that the building plot or height restrictions do not fit with the standardised shape or size increments of the modules, which reduces the rentability for developers. For the client an obstruction can be that no late changes can be made to the building design without major consequences to the building schedule and budget. The investor sees more risk in using modular construction, because of the risk of the manufacturer failing to deliver, which forms and obstruction for the use of modular construction.

The third question seeks to measure the current performance of modular multistorey student accommodations in the Netherlands. Performance is a very subjective topic, because it is dependent on the culture and preferences of people. With this is meant that performance is the capability of something to meet certain objectives. In this report important objectives of the built environment and DUWO have been considered to measure the performance. This resulted in five main objectives, which are: financial health, sustainability, affordability, student satisfaction and student wellbeing. To measure these objectives, the objectives have been split into key performance indicators (KPI). These KPI's have been used to measure the performance of three modular buildings. To measure this performance, the building data has been ordered in a comparison table per KPI, after which the data was analysed through interviews and supplementary building data. This resulted in insufficient, medium, and good performance of building aspects, which is used for the last sub-question.

In the last sub-question is looked at how the performance of modular construction can be increased. This is done by giving recommendations on how modular construction should be implemented for new built student accommodations so that modular construction performs better. These recommendations are based on the performance measurement from the previous sub-question and on interviews with experienced stakeholders in the field of modular construction. The recommendations serve as conversation starters for DUWO and other student housing associations that help people realise what still can be done to get more benefit out of modular construction and therefore reduce the obstructions. The recommendations that are given can be grouped under the objectives that were defined in the previous sub-question and involve many different topics such as: standardisation, contracting a manufacturer, procurement, program of requirement, total cost of ownership, maintenance, and design for disassembly.

From this entire research can be concluded that modular student accommodations perform well compared to traditional construction but compared to the goals of DUWO and the built environment, the performance should be increased. Therefore, the performance of the construction cost, building speed, maintenance cost, reusability, building lifetime, thermal comfort and ease of maintenance should be increased. To do this, DUWO needs to change their way of thinking about finances, sustainability, collaboration, and project delivery.

The aim of this research was to contribute to increase the uptake of modular construction and therefore also realising the benefits of modular construction. Through the recommendations that are given in this research for increasing the performance of modular construction, the obstructions of modular construction can be reduced while the advantages can be increased. These recommendations alone do not change the performance of modular construction. What is important to increase this performance is that these recommendations can get implemented in the policy and work method of a company. This means that more research will need to be done to execute the recommendations. Furthermore, this research only focused on 3D modular construction, while 2D modular construction also has a lot of potential. The advantages and obstructions for 2D and 3D modular construction are quite a bit different and therefore it would be good to do further research to the difference in advantages and obstructions between 2D and 3D modular construction. This way it is possible to make an informed decision between the use of 2D or 3D modular construction.

TABLE OF CONTENTS

VISUAL CONTENT

List of figures

List of tables

1 INTRODUCTION

1.1 CONTEXT

Currently the housing market in the Netherlands faces two major challenges. The first challenge is to build one million extra homes before 2030, to facilitate the population growth that is caused by immigrants, refugees and population increase through birth (CBS, 2020). In 2020 the government of the Netherlands reported that there was a shortage of 331.000 houses (Rijksoverheid, 2020). According to Oorschot (2021) the housing shortage is however quite specific to affordable houses which can be seen through the separation of haves (people that bought a house or have a subsidized rental house) and have-nots (people that rent in the free sector) in the market. The have-nots, who are people without own capital, must rent a house in the free sector that is too expensive. That the shortage is in the affordable houses also shows in the fact that the average Dutch person has 65m^2 of living surface available, while in Germany and other parts of Europe residents only have 45m^2 (Oorschot, 2021). This means that the Netherlands has more than enough houses, but only not for the right target group. Besides population growth, this shortage is caused by increasing needs due to increased economic welfare, reduced cohabitation, increasing environmental quality norms, and increased urbanisation (Delrue, 1969). The building sector cannot keep up with this enormous number of houses that need to be built as they currently only build around 70.000 houses each year (CBS, 2021). They cannot keep up with the housing demand due to insufficient building plots, labour shortages, building material shortages, an inefficient building process and a lack of political will.

The second challenge is the goal of the EU to transition to a climate-neutral society before 2050 (European Union, 2020). To achieve this goal, all sectors need to make changes including the building sector. Related to this, the Netherlands produces too much nitrogen and PFAS, which damages the environment and is unhealthy for people and therefore should be reduced (RIVM, 2020). Because the Netherlands produces too much nitrogen and PFAS, the building sector (and many other sectors) were recently hit hard by the restrictions that were imposed on building projects by the government, due to the stricter nitrogen and PFAS policy (Remkes, 2020). Many projects that had applied for an environmental permit were denied due to the lack of room that was available for producing nitrogen, which caused a lot of delays and cost the sector a lot of money.

Conventionally when the design phase is finished, a building is constructed at the construction-site by a contractor. This is commonly known as “on-site”, “site-built”, “stick-built”, “conventional”, or “traditional” construction (Kamali & Hewage, 2016). However, in the past few decades, new construction techniques were introduced, which expose the building sector to industrialization. These new construction techniques involve off-site construction, which refers to the production and preassembly of building components away from the construction-site. Modular construction is a form of off-site construction that ranges from 1D single elements to 3D volumetric modules that are room sized and come fully fitted out and ready for assembly on-site. According to Bertram et al. (2019), “modular construction involves producing standardized modules of a structure in an off-site factory, after which they are assembled on-site”. Due to the standardisation aspect and the production of the modules in a controlled environment, modular construction offers many benefits over traditional construction. Examples of advantages are construction time reduction, quality control, waste reduction, safety improvement and hazard and injury mitigation. Due to the many advantages, the use of modular construction has been increasing in popularity lately. There are however also some obstructions for the use of modular construction, which slow down the uptake of modular construction. Significant obstructions for the use of modular construction from the perspective of the project initiators are a lack of collaboration within the organisational structure, unsuitable building plot, misconceptions, and financial risk due to the possibility of the manufacturer failing to deliver.

Many different research papers state that modular construction is widely accepted as an efficient construction method because of the many advantages that it offers (Li, Al-Hussein, Lei, & Ajweh, 2013) (Bertram, et al., 2019) (Said, Ali, & Alshehri, 2014). Because of this efficiency increase, among others Stichting Eigen Huis, ABN Amro and the minister of housing, see modular construction as a solution for the current affordable housing shortage in the Netherlands, due to the increased building speed, reduced cost and the reduced need of skilled labour (Eigenhuis) (de Jonge, 2022) (ABN Amro, 2019). That modular construction can help increase the housing production has already been demonstrated in the past. After the second world war there was a need for speedy reconstruction and a need for social housing, and therefore construction companies used modular construction to make the building process go faster and more efficient (Bertram, et al., 2019). Research also states that unmet housing demand and the relative scarcity and cost of construction labour are the main drivers for modular construction to gain traction (Bertram, et al., 2019). Despite that 83% of the contractors in the Netherlands experience labour shortages (Cobouw, 2021) in combination with the apparent housing shortage, only less than 10% of the houses in the Netherlands are being built using modular construction (ABN Amro, 2019). This indicates that there is a real opportunity for the building sector to increase its efficiency by scaling up the use of modular construction.

The recommendation from the advice-committee about the nitrogen problems was to reduce the nitrogen production in the building sector though modular-, energy neutral-, circular- and nature inclusive building techniques (Remkes, 2020). Modular construction was proposed to decrease the nitrogen production, because it has many sustainability benefits such as reduced construction waste, reduced material use for on-site construction and reusability of the building components (Paliwal, Choi, Bristow, Chatfield, & Lee, 2021). These sustainability benefits are becoming more and more important as the demand for materials increases drastically, leading to a shortage of materials and price increases (Rijksoverheid, 2021). Companies that anticipate these changes and successfully adopt modular building techniques are better prepared for a future, in which regulations will most likely become more and more strict as the climate goal of 2050 approaches.

1.2 STUDENT ACCOMMODATION

Now that the context of the housing market is explained and how modular construction can contribute to this housing market, the type of housing that is used for this research will be elaborated upon. For this research student accommodations will be used. According to Lawson, Ogden, & Bergin (2012), student accommodations are ideal for modular construction due to the great level of repeatability that is possible and the room sizes that are compatible with transportation and manufacturing requirements. Despite this, according to personal communication with interviewee B1, only an estimated 30% of the student accommodations that have been built in the past five years use modular construction. Of course, this is already a lot more than the average of 10% for all buildings in the Netherlands (ABN Amro, 2019), but it should be even more considering the advantages of modular construction and that this function is highly suitable for modular construction. Just like the housing shortage in the Netherlands there is also a student housing shortage, which is estimated at around 26.500 rooms (Rijksoverheid, 2021b). Furthermore, the challenge of transitioning to a climate-neutral society before 2050 is applicable to student accommodations as well. These challenges in combination with the suitability of student accommodations for modular construction make student accommodations a good subject for this graduation research.

1.3 PROBLEMS HINDERING THE UPTAKE OF MODULAR CONSTRUCTION

As mentioned above, despite the many advantages of modular construction, the building sector still heavily relies on traditional construction methods, involving masonry, timber framework, scaffolding, and in-situ concreting (Ferdous, Bai, Ngo, Manalo, & Mendis, 2019). Because still such a big portion of the buildings are being built using traditional construction, the many different advantages that modular construction can provide are not utilized. This raises the question why modular construction is not used more frequently despite all the advantages and the stimulation from the context? There are a few problems that are related to this hesitant behaviour of the building sector.

1. There is a lot of confusion about what modular construction exactly is. Often (even in research papers) modular construction is seen as a fully fitted out volumetric unit that is produced in a factory and functions as a structural element of a building (Lawson, Ogden, & Goodier, 2014) (Said, Ali, & Alshehri, 2014). This definition however makes no difference with prefabrication which misses the element of standardisation and therefore diminishes/reduces most of the benefits that modular construction can offer. This confusion can lead to the choice for prefabrication of building elements, which doesn’t come close to the industrialisation aspect that modular construction can provide.
2. According to Kamali & Hewage (2016), many stakeholders who are involved in the construction process do not understand the advantages and obstructions of modular construction very well. This results in decisions about the use of modular construction being made based on anecdotal evidence rather than rigorous data. This also resulted from an interview with the Dutch student housing corporation DUWO, in which they indicated to have expectations about modular construction based on past experiences, but they lack facts on which they can base their decisions. A survey from the National Institute of Building Sciences confirmed this finding by pointing out that construction performance data would help increase the uptake of modular construction (National Institute of Building Sciences, 2018).
3. To realize the benefits of modular construction, different stakeholders will need to make a series of choices and change their way of working (Bertram, et al., 2019). These stakeholders are however not sure yet how to implement modular construction in their routine and therefore, for the most part, are currently reinventing the wheel of how to implement modular construction for every project. This lack of a standard greatly decreases the efficiency of modular construction and can potentially lead to not using modular construction. Therefore, according to a survey from the National Institute of Building Sciences and DUWO, there is a lack of implementation guidelines and design standards such as a standardized process design (National Institute of Building Sciences, 2018) (Interviewee B1, personal communication, January 11, 2022). The existence of these guidelines would increase the efficiency and thus realize more benefits of modular construction, which helps to increase the uptake of modular construction.

1.4 RESEARCH AIM AND RESEARCH QUESTIONS

The aim of this research is to contribute to increase the adoption of modular construction by addressing the above-mentioned problems. The conclusion of the problems is that there is a lack of knowledge among different stakeholders, which slows down the uptake of modular construction. In figure 1, the conceptual model for this research can be seen in which is illustrated that the context and the advantages of modular construction help with increasing the uptake of modular construction, but that the obstructions and the general lack of knowledge slow down the uptake of modular construction. This research will provide knowledge specifically for project initiators such as developers, investors and clients that will help reduce the obstructions and increase the advantages. This will be done by first defining a clear definition of modular construction. After that the advantages and obstructions for the use of modular construction are documented through literature research and interviews. Also, a performance measurement will be done to check the performance of modular construction, which will provide information that can be used to confirm or deny advantages or obstructions and thus provide extra knowledge on which decisions for the use of modular construction can be based. Furthermore, this performance measurement will be used to improve the performance of modular construction for student accommodations. This performance improvement will be realised by giving recommendations, which can serve as implementation guidelines. These recommendations will be based on literature and on interviews with experienced stakeholders. By increasing the performance of modular construction, the obstructions of modular construction can be decreased, and the advantages increased, which gives developers more reasons to choose for modular construction.

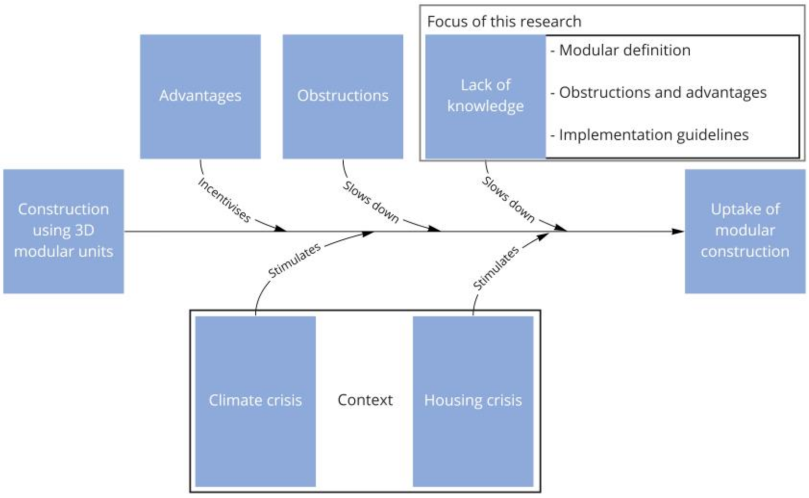


figure 1: conceptual model (own image)

To do this research, the following main question has been used:
"What is the current performance of 3D modular multistorey student accommodations in the Netherlands and how can this performance be increased?"

To answer this main question, four sub-questions have been used which are the following:

1. What is modular construction?
2. What are the advantages and obstructions of modular construction?
3. To what extent can modular construction currently satisfy the expectations of student housing associations in the Netherlands?
4. How can the performance of modular construction for student accommodations in the Netherlands be increased?

1.5 RELEVANCE

In recent years there have been many papers that investigated the topic of modular construction, because of the potential efficiency increase and positive environmental effect that it has on the construction sector. This means that a lot of information is available about obstructions and advantages of modular construction (Bertram, et al., 2019) (Thai, Ngo, & Uy, 2020) (Sun, et al., 2020) (Wilson, 2019), materials used in modular construction (Liew, Chua, & Dai, 2019) (Lawson, Ogden, & Goodier, 2014), the technology behind modular construction (Mills, Grove, & Egan, 2015) (Hou, et al., 2020) and the sustainability of modular construction (Lacovidou, Purnell, Tsavdaridis, & Poologanathan, 2021). This research that has been done has however lacked focus on providing practical implementations for increasing the efficiency of modular construction. This means that there is a lack in connection between the practical side and the theoretical side, which has led to a very slow adoption of modular construction. Therefore, this research will be a bridge between theory and practice by gathering available information from literature and combining this information with information from practice. This research will give project initiators (developers) recommendations that they can use to make decisions on how to implement modular construction in a project. Through this research that is based on literature and market information, project initiators will no longer solely have to rely on anecdotal evidence from colleagues or from past experiences.

1.6 SCOPE

The building type has a big influence on the advantages and obstructions of modular construction, as well as on the module design. Therefore, this research will specifically focus on student accommodations.

Efficiency of the construction process is for most stakeholders involved in the process beneficial, and most of the time supports the main goal of the stakeholder. For example, the main goal of DUWO is to provide affordable and safe accommodations for students. This goal is supported by increased efficiency of the building process through decreased building cost, which results in reduced rent and a possibility of quality increase for students. Therefore, this research will focus on 3D volumetric modules because they are the most efficient form of modular construction (Thai, Ngo, & Uy, 2020). Furthermore, the focus of this research will be on permanent buildings and will not consider temporary structures. The building height is also important to specify as this brings different material choices and building techniques with it. For example, a building higher than five floors cannot efficiently be built in wood anymore and if a building is taller than six floors a separate stability core is needed (Mills, Grove, & Egan, 2015). The height of the building has also some positive aspects for modular construction, because with more hight comes more repeatability which is beneficial for the advantages of modular construction. This shows that the height has a significant impact on the choices that need to be made to implement modular construction and therefore this research will focus on multistorey student accommodations that have a height of at least 5 storeys.

1.7 CASE

As mentioned in the previous paragraph, most information for this study will be gotten from the Dutch student housing association DUWO. DUWO will serve as a case in this research to gather data about the performance of modular student accommodations and about how to improve the performance of modular construction for student accommodations. DUWO is the biggest student housing association in the Netherlands with 33.000 student rooms. To realise these rooms, they already used modular construction for quite some buildings in the past, which means they can provide data that can be used for this research. This together with the size and the experience that DUWO has with student accommodations makes DUWO a good case for my graduation research. That DUWO will serve as a case in this research means that this research will not only be specific for DUWO, but that other developers and student housing associations can also use the results of this research.

1.8 DATA PLAN

To research how the performance of modular construction for student accommodations in the Netherlands can be increased, literature research, document reviews, student surveys and interviews will have to be executed. The data that is gathered through document reviews, student surveys and interviews can involve sensitive information and therefore this data will have to be handled carefully and confidentially. To keep this information confidential, interviews will not be added to the appendix so that everyone can read them. The summarized interviews, recordings and other confidential data will stay with the author of this graduation research, and they will not include any personal information of the interviewee. To enlarge the data set that researchers can use, the FAIR guiding principles were designed to ensure that all digital resources can be Findable, Accessible, Interoperable and Reusable (FAIR) (Wilkinson, 2016). To support this the following will be done:

- Interviews and other sensitive data can be requested by the author by sending an email to kevinvader@gmail.com. The author will contact the person to whom the data belongs and ask for consent to share the data
- The final version of this graduation research paper will be published on the repository of the TU Delft
- Interviews and other used data will include metadata so that when the interviews are reused the researcher can take the circumstances of the interview into account. Therefore, the interview setting, gender, profession, and date of the interview will be included in the interview transcript.

1.9 READING GUIDE

This graduation thesis consists out of six chapters that build on top of each other, with the first chapter being the introduction. This introduction forms the basis for the entire research, because it explains the relevance of the topic, context of the topic, problems that this research tries to solve and the scope of this research.

In the chapter that follows the introduction, more information is given about the methods that have been used to do this research, including data collection and analysis. In chapter three a literature review about topics that are useful for the implementation of modular construction can be found, which provides information that is mainly used in chapter six. In chapter four an overview will be given of the advantages and obstructions for the implementation of modular construction from the standpoint of different stakeholders. In chapter five, the performance of three modular buildings and one traditional building will be measured. This is done through determining specific objectives that are split in different key performance indicators (KPI), that are measured and held against a goal, which led to insufficient, medium, and good performance. In chapter six, recommendations are given to increase the performance of the modular buildings.

2 RESEARCH METHOD

In this chapter the methods for acquiring the required data for this graduation research will be discussed.

2.1 LITERATURE RESEARCH

In the first part of this graduation thesis, literature research is done to get more acquainted with the topic of modular construction. Modular construction has recently increased in popularity and therefore quite a bit of literature such as graduation researches, research papers, explorative interviews and webinars were available for me to study or execute. Getting a good understanding about the state of the art of modular construction supports the rest of this research, because it makes that more educated questions can be asked when doing interviews and it helps with analysing the case study buildings. Furthermore, it provides possible solutions for improving the performance of modular construction. Through the literature review part, sub question 1 and 2 should be answered.

The literature review starts with determining the definition of modular construction which also defines the scope of this research. When the definition of modular construction is clear, elements such as standardisation, flexibility, building life, sustainability, lifecycle costing and the advantages and obstructions of modular construction will be discussed based on literature. This literature review gives an understanding of what aspects should be considered when using modular construction.

2.2 EMPIRICAL RESEARCH

In this research the performance of modular construction for student accommodations will be measured and solutions will be proposed to increase this performance. This information cannot be found in literature and therefore own observations, case studies and interviews will need to be used to gather information. Because of this can be said that empirical research will be used for a big part of this research. The methods that will be used to gather the information will be qualitative methods. Qualitative methods have been chosen, because they can give an explanation and a better understanding about the performance of modular construction and provide solutions to improve this performance. The empirical part of this report is split into current performance and performance improvement, which will be discussed below.

2.2.1 CURRENT PERFORMANCE

The performance section of this report measures the performance of modular multistorey student accommodations in the Netherlands. To do this, important objectives from DUWO and from the entire built environment had to be determined. Therefore, interviews were held with different disciplines and departments within DUWO to get a clear overview of what are important objectives for DUWO. The interviews that were done can be found in table 1, of which mostly the buyers group was used for this section. Furthermore, the policy document of DUWO is used in which they specify what are important objectives for DUWO as an organisation. These objectives from DUWO are important, but it is possible that some important objectives with respect to the future, environment, or something else are missing. Therefore, also objectives from the entire built environment were gathered through literature research, to get a more holistic overview of important objectives. These objectives were translated into measurable key performance indicators (KPI) that can be used to measure and compare the performance of buildings. For every KPI a goal was defined based on the "werkplan" of DUWO, interviews or literature research.

To do a performance measurement, for every KPI data needs to be gathered. Therefore, a selection of DUWO buildings was made that are suitable for this performance measurement. For this measurement three modular buildings were chosen, and one traditional building was chosen. A traditional building was included in the analysis part of the performance measurement to have a standard to which the modular buildings can be compared. For the modular buildings the selection criteria were as follows:

- the building age should not be older than 10 years
- the building function should be for at least 90% student housing
- the building height should be at least 5 storeys
- the buildings should be constructed using 3D modular construction
- the buildings should be classified as permanent and not temporary.

These selection criteria have been put in place because this will make sure that the buildings are similar and therefore a fair comparison can be made. These selection criteria follow the limitations that have been implemented to this research in the scope definition in chapter 1. The choice for the traditional building was simpler, because one modular building was copied from a traditional building and therefore it made sense to use this traditional building, so that it could serve as a reference for the modular buildings.

For every KPI, the data per building was gathered. This data was gotten from data storage at the DUWO cloud, but also a lot of information had to be requested by the specific DUWO department, such as maintenance, energy consumption, building cost and student wellbeing. Most buildings are situated in Amsterdam, but one building is situated in Leiden, which means that different people had to be approached for this information. Furthermore, to get an indication about the student satisfaction, a survey was set out under the students that lived in two of the four buildings. The sample size for this survey were 418 students that were divided over the two buildings. Of these 418 students 42 students responded, which means there was a response rate of 10%. In this survey the students were asked how satisfied they were with different aspects of their room such as thermal comfort, acoustic comfort, ease of maintenance, the bathroom, kitchen, and the overall room. In this survey they could rate their satisfaction from 1-5, but there was also a possibility to give a comment on this rating so that this could be used to understand the rating.

All data was implemented in a comparison table in which the data per KPI could be compared for all four buildings. Based on this comparison table an analysis could be made of the data. For this analysis, different people within DUWO were approached to clarify some results. Based on this analysis and the goals that were formulated earlier the performance of the buildings could be determined per KPI. This performance resulted in building aspects that performed well, but most aspects performed worse than the goal. What has to be taken in mind is that the buildings have been built quite some years ago, which means that standards back then were different and therefore the buildings don’t live up to the goals of right now.

2.2.2 PERFORMANCE IMPROVEMENT

In the performance improvement part of the report, recommendations have been done to the implementation of modular construction that can improve the performance of modular construction. To get to these recommendations, interviews with professional stakeholders in the field of modular construction were done (see table 1). These interviews gave insight into how modular construction should ideally be executed and implemented by DUWO. The questions that were asked in these interviews were based on the literature review that was done in the literature part of this report. These questions involved topics about standardisation, flexibility, lifespan, procurement, advantages, obstructions, sustainability, reusability, and installations. To be able to learn the most from the interviews and delve deeper into new insights that were gained from the interviews, the questions that were asked in the interviews changed. This means that as new topics are discovered through the interviews, these new topics were included in the questions for the next interviewee. This way new insights could be gained and recommendations that were based on previous interviews could be evaluated by another interviewee. This ensured that the recommendations that were done in this report are evaluated by multiple interviewees, which makes them more trustworthy. Furthermore, all recommendations were evaluated by interviewee B1 and B5 which are my graduation supervisors at DUWO and some recommendations were reviewed by specific disciplines within DUWO that had more experience with the specific topic.

2.2.3 INTERVIEWS

For the entire empirical part of this research interviews had a central place in the data gathering part of this report. The reason that interviews had a central place in the data gathering part is that there is not much information about performance improvement of modular student accommodations available in literature, and therefore this information had to be acquired from the market. To determine the current performance of the modular buildings, the objectives and expectations of DUWO in relation to modular construction were partly determined through interviews. To have a wide variety of perspectives, different disciplines within DUWO were interviewed. The interview information sheet that was sent to the interviewees before the interview started can be seen in Appendix B: information sheet interviews.

The most interviews were done to determine the possibility of a performance increase for modular construction. The interviewees were selected based on their experience with modular construction and therefore many modular manufacturers were interviewed. These modular manufacturers know what is important for them, so that they can improve the performance of their product, which makes them a good party to interview. Furthermore, also some advisors were interviewed to give some information on specific topics. Lastly, different disciplines within DUWO were interviewed to get some specific information about for example finances, maintenance and procurement processes. All these different interviews provided the information to give recommendations about how modular construction should be implemented so that the performance of modular construction for student accommodations can be increased. The interview information sheet that was sent to the interviewees before the interview started can be seen in Appendix A: Information sheet interview.

In in table 1 an overview can be found of all official interviews that were held for this research. All these interviews have been summarized so that the information from the interviews can be verified and that extra information that was not relevant for this research can later be used for another research. The interviews have not been transcribed, because it does not add any value to this research, because a qualitative research method has been used. If a quantitative research method was used, the interviews would have been compared and analysed and therefore transcribing would have been useful. The goal of these interviews was not to compare them, but to find new insights which could be followed up with other questions. Therefore, it is more time efficient to summarize the interviews so that the interview information is already filtered to useful information, which makes searching information easier. In the text of this graduation research, information that came from interviewees will be referenced as follows: “interviewee #”. The # is replaced by the letter + number of the interview that can be found in table 1. This way of referencing to interviews will keep the document clean and readable. Furthermore, also a lot of personal communication was done to clarify some findings or to ask for specific solutions to increase the performance. These personal communications have been referenced to in the text using the words personal communication. This personal communication has not been recorded nor summarised and therefore has been separated from the official interviews.

table 1: Overview of interviews

group	#	Company	Profession	Date
Buyers	B1	DUWO	Developer 1 student housing	07-02-2022
	B2	DUWO	Project manager	07-02-2022
	B3	DUWO	Developer 2 student housing	08-02-2022
	B4	DUWO	Supervisor	08-02-2022
	B5	DUWO	Director real estate	08-02-2022
	B6	DUWO	Project leader asset management	10-02-2022
	B7	DUWO	Supervisor installations	12-02-2022
	B8	DUWO	Policy manager	15-02-2022
	B9	DUWO	Financial director	02-03-2022
	B10	Rochdale	Board member	24-03-2022
Suppliers	S1	Jan Snel	Modular manufacturer	18-10-2021
	S2	Ursem	Modular manufacturer	25-02-2022
	S3	Van Wijnen	Modular manufacturer	15-03-2022
	S4	Chainable	Kitchen manufacturer	16-03-2022
	S5	Genius Homes	Modular manufacturer	18-03-2022
	S6	MOOS	Modular manufacturer	25-03-2022
	S7	Finch buildings	Modular manufacturer	08-04-2022
Advisors	A1	Atelierpro	Architect	18-02-2022
	A2	Nieman	Installation advisor	05-04-2022

3 LITERATURE REVIEW

In this chapter, the information that was found through literature research, is discussed. This information gives an overview of the state of the art of modular construction and forms the basis for the rest of this graduation research. Multiple topics are discussed, such as the definition of modular construction, flexibility, total cost of ownership and lifetime. These topics are used in chapter 6 to give recommendations to improve the performance of modular construction for student accommodations.

3.1 MODULAR CONSTRUCTION DEFINITION

The term modular construction is often used in combination with off-site construction or prefabrication. These three terms can be categorized as Modern Method of Construction (MMC). This MMC focuses on off-site construction techniques which increase efficiency, quality, and sustainability. In the paragraphs that follow, the definition of modular construction will be elaborately discussed.

To get an idea of what modularity means it is important to look at what the dictionary says about the term modular. According to Cambridge Dictionary (n.d.), modular is defined as “consisting of separate parts that, when combined, form a complete whole”. Merriam-webster (n.d.) defines it as “constructed with standardized units or dimensions for flexibility and variety in use” and Dictionary.com (n.d.) defines it as “composed of standardized units or sections for easy construction or flexible arrangement”. Based on these definitions can be said that modularity involves (1) separate parts that can be combined to form a whole, (2) standardisation and (3) flexibility.

The term modular can be used in many different disciplines such as: biology, automotive, computer science and in the building sector. Therefore, it is important to use literature to determine what is specifically meant with modularity in the building sector. According to Thai, Ngo & Uy (2020) modularity in construction is closely related to prefabrication, whereby building components are fabricated in a factory and transported to a construction-site for installation. They divide prefabrication in three categories, which are: 1D single element, 2D panelised system and 3D volumetric system. This doesn’t mean that modular construction and prefabrication are the same concept as is often illustrated in research papers (Lacovidou et al. (2021)). These papers describe modular construction as volumetric units that are fitted out in a factory off-site and are used as structural elements of the building (Lawson, Ogden, & Goodier, 2014) (Said, Ali, & Alshehri, 2014). This definition however has no difference with the definition of prefabrication, and therefore will not be used in this research. A different definition has been established by Temel & Kahraman (2018) who indicate that modular construction uses prefabrication, but that it adds the dimension of standardisation and interchangeability to it. This has many advantages over prefabrication, because through standardisation of the production process the cost per unit can be lowered while keeping the ability to handle the uniqueness of buildings and thus allowing for mass production. This is achieved by combining a limited number of standardized modules into a broad variety of different building designs due to the flexibility that modular construction offers. In this research the following definition for modular construction will be used: “modular construction involves producing standardized modules of a structure in an off-site factory, after which they are assembled on-site” (Bertram, et al., 2019). This definition is used, because it combines the definitions from the dictionary that were discussed in the previous paragraph and provides a readable and usable definition of modular construction. What is still unclear from this definition are the terms “modules” and “standardisation”. Therefore, in the next paragraphs the term module will be discussed and after that standardisation.

3.1.1 MODULE

Gosling et al. (2016) defined a module as a construction unit that is part of a wider system, which can be integrated through pre-planned interfaces. This unit however can have different levels that vary in measurements, which are according to Gosling et al. (2016) building, elements, components, and sub-components. These different levels can be used for both off-site and on-site construction. Examples and definitions of these different levels can be seen in table 2.

Jan Delrue (1969) has done research to the industrialisation of the building sector by designing a modular measurement system. In this research he defines multiple levels of building modules that can be used to make the building process more industrialised and thus more efficient. In contrast to Gosling who defined only four levels of building modules, he determined 12 different levels, of which 7 could be used to industrialise the building sector (table 3). Both researchers saw that modularization involves breaking up a system into parts that follow standardized interfaces, rules, and specifications (Gosling et al., 2016). The difference between these two researchers is that Jan Delrue made a more specific overview of the parts that a building can be broken up into and Gosling stayed more general. In this research the focus will be specific to entire student accommodations that will be modularized, which in turn again are assembled using lower-level modules. Gosling did not make a distinction between modules that enclose multiple spaces and modules that only enclose one space, as he defined both as “elements”. Jan Delrue made a differentiation between the two with the terms building cells and building sector cells. Because this research is specific to student studios, that involve multiple rooms (bathroom, kitchen, living room), it is important to be able to make a differentiation between modules that enclose a single room or multiple rooms. Therefore, the terminology of Jan Delrue will be used in this research. This means that a student room that includes a bathroom is called a building sector cell.

table 2: Different module levels adapted from Gosling et al. (2016)

Level		Definition			Example
4	Building	Entire building is modularized and transported to the site.	Volumetric	3D	Complete house
3	Elements	Large repeatable segments that repeat across a development: they have a structure and can stand alone and can be the main chunks of which a project is composed. They are connected to a specific function.	Volumetric	3D	Bedroom, bathroom, toilet
2	Components	Fully or partially finished building elements that form part of larger structural elements assembled on-site	Non-volumetric	2D	Wall, floor, and roof
1	Sub-components	Lowest level, likely to be used by other areas within a building, eighter at the component or element level.	Non-volumetric	1D	Beams and pillars

table 3: Different module levels adapted from Delrue (1969)

Level		Definition		Example
0	Raw materials	Natural or artificial material that doesn’t have a form that has a relation with the to be formed building material.	1D	Iron ore, wood, gravel, cement
1	Building materials	Small building materials that due to repetition form building elements Building materials that does not yet have definitive dimensions Building materials that do not have a set length and width, but have a set thickness	1D	Bricks Extrusion profile

				Wooden sheets
2	Components	At least two dimensions are in relation to a functional or technical activity. The components have a set shape, and they determine an activity and not the shape of a room. They are suitable for standardisation.	1D	Doors, kitchen, windows, bath Radiator
3	Elements	Two dimensions determine the shape of a room, third dimension is determined functionally or technologically	2D	Wall
4	Sub-elements	One dimension is related to the room, other two dimensions are determined on lower level (technological or functional)	2D	Ytong
5	Building segments	At least one dimension is determined by the sector and other dimensions are functional or technologically determined. Building segments can realise a building structure and close it off. An entire building cannot consist solely out of building segments.	2D	Beam, tt-floorsegment
6	Building cells	Made through the assembly of building elements. The three dimensions of building cells determine the shape of a room.	3D	Shower cell, sleeping room, kitchen
7	Building sector cells	The three-dimensional building sector cells are the highest possible form of a producible building part. The structure should be independent from the infill or the sector.	3D	3d volumetric unit
8	Building	A whole building that cannot be constructed off-site, due to transportation issues.	3D	

Both researchers defined different levels which can be divided in volumetric and non-volumetric modules (figure 2), which can again be divided in 1D,2D and 3D (da Rocha & Kemmer, 2018). With 3D volumetric modules, up to 95% of the work can be done in the factory, which reduces the assembly time on-site (Thai, Ngo, & Uy, 2020). With 2D non-volumetric modules 75% of the work is done in the factory, but still quite a bit of assembly is needed on the construction-site (Thai, Ngo, & Uy, 2020). 1D non-volumetric modules can be pre-cut or prefabricated in a factory, but most of the assembly work must happen on-site. If more work is done off-site, more benefits of off-site construction can be achieved. This means that 3D volumetric modules are the most efficient form of modular construction. It has however some disadvantages, which are: size limits due to transportation and low possibility of customization. Also, 2D non-volumetric modules offer far more flexibility than 3D volumetric modules. To fully achieve the benefits of each system, the two systems can be combined into a hybrid version (Bertram, et al., 2019) (Thai, Ngo, & Uy, 2020).

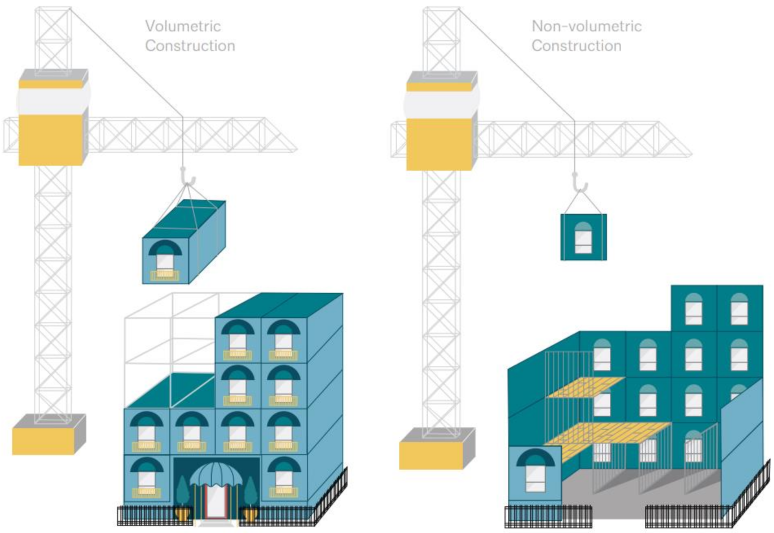


figure 2: Volumetric and Non-volumetric construction (Wilson, 2019)

3.1.2 STANDARDISATION

Repetition is advantageous for modular construction, because due to repetition a more efficient working process can be realised. Therefore, standardisation should be implemented in buildings well beyond individual large projects, so that industrialisation of the building sector becomes possible (Bertram, Mischke, & Sjödin, 2019). The question however is, to what extent should standardisation be implemented in the manufacturing of the modules? Delrue (1969) made a differentiation between open industrialisation and closed industrialisation for the building sector. With open industrialisation, he meant the use of standardised components with which a gamma of different buildings and building functions can be constructed. To achieve this, a common measurement system is of great importance together with common connections and quality. With measurement system, an addition of a standard size is meant, for example with prefab concrete floors it is common to use 900mm as a standard size, which produces 5600, 6500,7400 etc. When this kind of standardisation would be possible to realize, manufacturers can have a very large market reach, which allows them to specialise and achieve economies of scale. This has the advantage of lowered production cost and due to pre-order manufacturing the market cycle risk is reduced. With closed industrialisation, a manufactured component should as well be standardized in measurement system, connection, and quality, but this standardisation will be specific for a building function. The aim should be to reach open industrialisation in the building sector, because with this broad form of standardisation, more advantages of modular construction can be achieved, which will move more stakeholders to use modular construction. Most of the advantages of modular construction come from economies of scale, which reduces cost and increases efficiency through spreading of fixed cost, specialisation, low inventory ratio and more effective use of buildings and machinery (Besanko, Dranove, Shanley, & Schaefer, 2007). To achieve this, the mindset of the construction industry should shift from a focus on unique one-of-a-kind projects to a more standardized approach (Aapaoja & Haapasalo, 2014). This doesn't mean that all buildings will be the same, but that several standard modules can be mixed and matched to build custom designs. This is also called mass customization, which combines the flexibility and personalization of custom-made products with the low unit cost of mass production.

3.2 IMPORTANT BUILDING ASPECTS

When implementing modular construction, different building aspects need to be considered. Examples of these building aspects are the height, the lifetime, the use time, the flexibility, the sustainability, and the total cost of ownership of the building. In this chapter, these topics will be discussed based on information from literature, which will give some background information about how to implement modular construction. This information will later in this report (in chapter 6) be used to give recommendations on how DUWO should implement modular construction for their buildings. Because this research focuses on modular construction for student accommodations, first some trends for using modular construction for student accommodations will be described based on information from DUWO. Modular construction has already been used for quite some time for student accommodations, which started as temporary buildings that would be removed after a few years. Now modular construction is slowly maturing, and more and more permanent modular buildings are being built. figure 3 shows all modular student accommodations of DUWO, in which clearly can be seen that modular construction is moving from temporary constructions to more permanent buildings and that the frequency is increasing. Also, can be seen that for permanent buildings mostly concrete and steel is used or a combination between steel and wood. Also, due to the cellular-type building structure, all modular buildings that have been made by DUWO are made using 3D modular construction. What also can be seen is that the permanent modular buildings have become taller through the years and that temporary buildings that have been used are maximum four storeys high.

No.	Name	Vestiging	Type	Building year	Exploitation horison	End of exploitation	Storeys	VHE's
1117	Leeghwaterstraat/Feldmanweg	Delft	Spacebox	2003	Temporary	2016	3	123
1117	Leeghwaterstraat/Feldmanweg	Delft	Prefab Cabin	2003	Temporary	2016	3	100
3201	Verlengde Wassenaarseweg	Oestgeest	3d mkw (COA)	2005	Temporary	2013	3	544
4605	TT Melaniaweg	Amsterdam	Prefab Cabin	2004	Temporary	2018	2	77
4605	MS Oslofjordweg	Amsterdam	Prefab Cabin	2005	Temporary	2019	3	303
4618	Stavangerweg	Amsterdam	3d mkw (COA)	2006	Temporary	2015	2	380
4620	Zuiderzeeweg 30-40	Amsterdam	3d mkw (COA)	2006	Temporary, now permanent	2025	2	204
1129	Leeghwaterstraat West	Delft	Ursem m1	2009	Permanent		6	186
2490	Stamkartstraat (LUCTH)	Den Haag	Prefab Cabin	2010	Temporary, now permanent		4	122
3265	Hildebrandpad	Leiden	Ursem m2	2011	Permanent		8	504
4724	Uilenstede Oost 2	Amsterdam	Ursem m2	2014	Permanent		11	233
4646	Darlingstraat (Spinoza Campus)	Amsterdam	Prefab Cabin	2015	Temporary	2030	4	550
4643	Dennerodepad (Spinoza Campus)	Amsterdam	Prefab Cabin	2012	Temporary	2027	4	700
X-it	Laan van Spartaan	Amsterdam	Ursem m3	2018	Permanent		14	347
2000	Waldorpstraat	Den Haag	Ursem m3	2023	Permanent		?	408
1143	TU Midden-Noord (veld 2, B vd Polweg)	Delft	Jan Snel	2023	Permanent		?	136
4000	Wisselweg	Almere	Ursem m3	2023	Permanent		?	408
4647	Laan van Kronenburg 7 (Uilenstede)	Amsterdam	?	?	Permanent		Max. 15	600?

Prefab Cabin (Plegt Vos)	Concrete floor with steel frame. Look and additiontechnique of shipping containers.
3d mkw (COA)	Dwellings for 4 students made from 2d or 3d wooden elements (multiple manufacturers, most of 3D Ursem)
Ursem m1	Concrete floor with steel frame and wooden infill
Ursem m2	Concrete floor with steel frame and wooden infill, stacked untill 8 storeys after that steel construction frame
Ursem m3	Concrete floor with concrete columns and wooden infill. Can be stacked untill 23 storeys

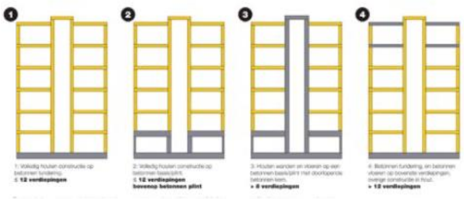
figure 3: Modular projects built by DUWO

3.2.1 MULTISTOREY

As could be seen in the previous paragraph, the construction height of modular buildings that are built by DUWO is increasing. This is necessary if modular construction wants to compete and possibly even replace traditional construction. The material that can be used for the structure of a 3D volumetric module depends mostly on the height of the building (Thai, Ngo, & Uy, 2020). This is because steel, wood and concrete have different structural material characteristics. For example, wood has a very low vertical and horizontal loading capacity, which makes wood not a good option to use as structural element for tall buildings. Concrete however has a very high vertical loading capacity, but a low horizontal loading capacity. Therefore, concrete is a very suitable material to use for constructing tall buildings. The disadvantage is that long spans are not possible with concrete without making the beams very colossal. Steel has a high strength-to-weight ratio and a good vertical and horizontal loading capacity, which means that columns and beams can be made very slender. Because the height of the building has a big impact on the choice for materials it is important to specify that this research will look at multistorey student accommodations. Multistorey buildings also have an advantage for the use of modular construction, because with tall buildings comes a lot of repeatability, which makes standardisation possible on a building level. As mentioned before, we should however aim for standardisation well beyond individual large buildings. The choice for materials is however not only determined by the structural characteristics of the material. Also cost, reusability, transportation, environmental impact, weight, fire resistance, acoustic performance etc. have to be considered when choosing the material. Therefore, when choosing a material for a modular unit, these aspects have to be taken into consideration and this very often results in a mix of materials that is used to construct the module. For example, steel is not fire-resistant or soundproof, like concrete. To combine the advantages of both steel and concrete it is possible to use a steel-concrete composite (SCC) structural system that combines the use of concrete and steel, by pouring concrete into steel tubes (Liew, Chua, & Dai, 2019). This results in a flexible and adaptable system that has the capacity for dismantling and reuse (Ahmed & Tsavdaridis, 2019). Based on interviewee S2, this is however not used very often, because this technique is more expensive and wider columns are needed than when just concrete is used. This is because to make steel fire-resistant normally they are made fireproofed with fireproof sheets, which are very inexpensive. The steel columns have to become wider because the concrete in the steel column has to be reinforced and this reinforcement needs enough cover. Also, the weight of materials has to be considered when choosing a material. for example, concrete weighs more than wood and the weight of the module has great impact on the transportation cost. This is because the cost of the tower crane can increase by up to 60% if the module weighs more than 20 tonnes (Bertram, et al., 2019). In figure 4 an overview can be seen of some material combinations that are possible for the structural module.

To deal with lateral forces, depending on the hight of the building a pre-made core can ensure the stability of the building (Mills, Grove, & Egan, 2015). The modules should be connected to the core, and they should be connected among themselves. This connection system should facilitate disassembly, so that the individual modules can be reused at the end of the building life. For building that are not higher than six storeys, the modules can be designed as self-stable, which means that they will be able to withstand lateral forces and no stability core is needed. Furthermore, to make sure the building is structurally safe, all modules need to be able to resist vertical loading over the full height of the building.

	Hoofdraagconstructie	Wand	Vloer	Bouwlagen
1	**Volledig hout**			
1A	HSB	HSB	HSB	3*
1B	LVL	LVL	LVL	5*
1C	CLT	CLT	CLT	5*
2	**Hout + beton**			
2A	CLT + BETON	CLT	Beton	10*
2B	HSB+ BETON	HSB	Beton	10*
3	**Volledig beton**			
3A	Beton	Beton	Beton	23*
3B	Beton + stalen windverbanden	Beton+staal	Beton	5*
4	**Staal + beton**			
4A	Staal + beton	Stalen kolommen	Beton	
4B	Staal + beton	Stalen kolommen	Beton+Staal	



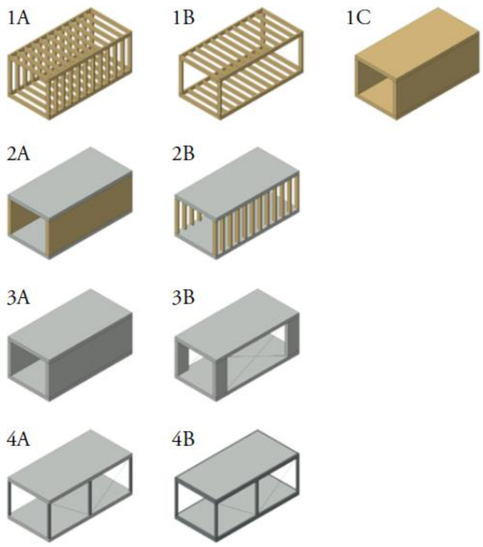


figure 4: Overview of different material combinations in modules adapted from Studio9dots

3.2.2 USE-TIME

As could also be seen in the projects of DUWO (figure 3), historically the main use of 3D volumetric modules was to construct temporary buildings, due to the possibility of easy reuse and the quick assembly time on-site (Lawson, Ogden, & Goodier, 2014). These modules can be used for all kinds of building functions, to temporarily fill the need for shelter until something more permanent is built. These temporary buildings are suitable for a shorter period such as months or a few years. Because they are of temporary nature, the modules don't need to adhere to all building rules that are defined in the building codes but have separate rules with lower standards. According to the building codes a temporary building is a building that will be in one place for maximum of 15 years (Rijksoverheid, n.d.). Because these buildings can easily be relocated or extended, they are not fastened to a foundation. This together with the short use time can be seen as the main criteria to differentiate permanent and temporary construction. Because the temporary modules need to be reused in different locations and for different functions, according to interviewee S1, the modules are very much standardized in the sense that aesthetic aspects are turned down to a minimum. The next step in use-time is semi-permanent modules, which are usually used for a few years up to the maximum of 15 years that is defined in the building codes. With these modules a more custom design is possible such as differentiating in sizes and finishes, but the general detailing will be the same. The last step in the use-time spectrum is the permanent modules. These permanent modules adhere to the requirements of a permanent building, which make that they can provide a higher acoustic, thermal and visual comfort as well as better air quality. Also, more design variations can be made due to the expected long use-time and thus longer time to get returns on the building. In order to let modular construction contribute to the housing shortage and the climate crisis it is important that modular construction can be a substitute for traditional construction. Therefore, the focus should be on permanent modules that are standardized and comply with the building codes. This is very important, because for modular buildings to be attractive, they must perform the same or better than traditional buildings.

3.2.3 LIFESPAN

The use-time of a building doesn't say much about the lifespan of the building. The module can be labelled to be temporary, but is the module really at its end of life after 15 or 30 years? Most likely parts of the building are at the end of its physical life, but other elements can possibly be used for much longer. Also, some building elements still function fine, but have to be changed, because the users just don't like it anymore. Therefore, the building lifetime can be split in two kinds, which is technical and functional building lifetime (Delrue, 1969). The technical lifetime is how long the building can physically stand and be used, which ranges between 50 and 100 years. The technical lifetime of a building depends on the used building materials and de quality of the construction. The functional lifetime however is much shorter and depending on the function ranges between 5 and 20 years. The functional lifetime is the time that the infill of a building is useful. For dwellings this functional lifetime is the same as the duration of a specific family situation, which is about 20 years. As can be seen, technical and functional lifetime are not the same in length, which means that before a building must be demolished due to technical failure it already becomes obsolete, because the building use has changed. According to Brand (1995) change of building use isn't even across the whole building and therefore he expanded the sheering layers concept from Frank Duffy. This sheering layers concept splits a building in different layers that evolve in different time frames. In figure 5 the sheering layer diagram from Brand (1995) can be seen, which is split into the following layers:

1. Site: the building lot that is eternal
2. Structure: the structure and load-bearing elements of a building are difficult and expensive to change, therefore they can last decades to centuries. However due to poor incorporation of flexibility in the design of buildings, such as most buildings built after the second world war, the buildings cannot live up to the current standards and are demolished prematurely. This layer is also seen as the building.

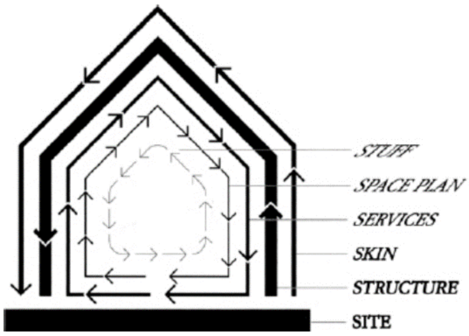


figure 5: sheering layers, adopted from (Brand, 1995)

3. Skin: the skin is the face of the building and goes out of style or gets outdated. Therefore, the skin is changed once every +-20 years to keep up with fashion or technology
4. Services: these are the installations of a building, such as ventilation, heating, cooling, electrical wiring, and elevators. These installations wear out or become obsolete due to new innovations. Therefore, their lifetime is about seven to fifteen years
5. Space Plan: Interior layout that involves walls, ceilings, floors, and doors. It depends on the building function how often this is replaced. It can range between 5 years to 30 years.
6. Stuff: this is the furniture such as chairs, phones, lamps, and beds, which change with the seasons and current trends.

In the sheering layers concept, the theory of J. Delrue can be seen in the fact that most layers (3,5,6) change because of their functional lifetime and not because of their technical lifetime. Therefore, buildings (structure) should accommodate change by incorporating flexibility in their design.

3.2.4 FLEXIBILITY

Flexibility in a building can be defined as the ability to change the infill without making changes to the structure of the building (Delrue, 1969). This means that the structure of the building should be designed to accommodate change. The advice from Brand (1995) was to oversize the carrying capacity of a structure so that new floors can be added. This same thing is used by the SUM team, which uses the oversized carrying capacity of tenant flats to add some extra floors/apartments to the building. This demonstrates that oversizing the carrying capacity of a structure can be very beneficial in the future when layers of a building- or client wishes change. To solve the problem of different technological and functional lifetimes, the infill of a building should be made flexible. In the book "de dragers en de mensen" J. Habraken separates a building in two categories, which are the support and the infill (Havik & Teerds, n.d.). With the support of the building, he means the communal spaces (entrances, corridors, stairwells, meeting spaces, facade), which are the job of the architect to design so that people will cherish them. The infill are the private spaces of the building users, which he thinks should not be designed in detail by the architect, but the architect should provide a framework/context in which the users can define the infill. Through this way of thinking he introduces the separation of control and the time dimension into the design. This time dimension is important, because people and building-use (functional lifetime) change over time and therefore the infill should be designed with optimal flexibility in mind (Havik & Teerds, n.d.). When using modular construction flexibility can be incorporated in the module design by making a structure that can accommodate change. This means that the structure should be oversized and slender, meaning that it should be corner-post bearing and not wall-bearing (Liew, Chua, & Dai, 2019). This concept can be translated into a module that consists only out of columns and beams which ensures maximum flexibility. This basic module should act as a framework in which 2D standardized non-volumetric modules can be placed according to the need of the client. Geraedts (2008) identified four key performance indicators (KPI's) for flexibility, which are: partitionability, adaptability, extendibility and multifunctionality. These four KPI's are achieved through the above-described 3D volumetric module, because the building made from these modules can be adapted by adding or subtracting modules, which makes it possible to easily change the function of the building. This shows that a building using 3D volumetric modules can be flexible, custom designed and efficient to produce.

3.2.5 TOTAL COST OF OWNERSHIP

The initial construction cost of a building only represents about 20% of the total building cost over its lifespan, while the other 80% is spend on maintenance-, operating-, refurbishment- and demolishment cost (Demetriou, Kamath, & Mahaney, 2016). Traditionally initial construction cost gets most of the focus, while during the building life a lot more cost can be saved by spending a bit more upfront on construction cost. Especially for companies that develop and operate buildings it makes financially sense not to only look at the initial cost, but at the entire cost of the building during its lifetime. Total Cost of Ownership (TCO) is a financial management strategy that measures all the costs of the building during its complete life cycle, so that they can be managed and reduced as much as possible (APPA, 2016). Companies can reduce this TCO by using a cost-focused methodology that supports the design and implementation of specifications at the lowest TCO across the end-to-end lifecycle, which Is also called cost engineering (Cheung, Günthner, Ibánez, & Mohr, 2019c). Cost engineering is about balancing initial building cost, maintenance cost, operating cost, refurbishment cost and demolishment cost over the entire building life, while considering the quality of the building (FMlink, n.d.). For cost engineering to be possible, hands-on experience is of great importance, which makes that the people that operate and maintain buildings need to be involved in the design stage of a building. When designing for a low TCO the following aspects could contribute:

1. Incorporating flexibility in the building structure to reduce possible future cost of changes

2. Increasing the lifetime of elements of which their technical lifetime is shorter than their functional lifetime. Based on the sheering layers model this is true for services and for the structure of a building if it is designed for flexibility
3. Design for disassembly makes reuse of building elements possible once the building is at the end of its functional life. This makes that demolition costs can be reduced, and the building has a rest value.
4. Designing for energy efficiency of the building can make a big difference, because the cost for heating and cooling during operation can be greatly reduced.

3.2.6 SUSTAINABILITY

Because the goal of the EU to be completely energy neutral by 2050 approaches, rules about sustainability are being increased. These rules have a big impact on the realisation of buildings for all stakeholders and building types, because these rules require better insulation, less fossil energy use and reduced environmental impact of materials. These rules change the way the building sector used to build and generally increase the initial building cost. The relatively new rule that was implemented at the start of 2021 is called the BENG. The abbreviation BENG stands for nearly energy neutral building which already says that the goal of BENG is to make energy neutral buildings which reduces the CO_2 emission of the building. As illustrated in the previous paragraph about the TCO, the BENG rule has a positive effect on the TCO calculation, because the building becomes a lot more energy efficient. BENG replaces the old energy performance coefficient (EPC) and the energy performance advice dwellings (EPA-W) (Isover, n.d.). The BENG is being determined based on the following three indicators:

1. The first indicator is the maximum energy consumption in kWh/m^2 usable floor area (GO) per year. This indicator gives a maximum amount of energy that a building may use for heating and cooling. The goal is to reduce the energy consumption of a building by optimizing the quality, orientation and shape of the building envelope, for which the following aspects are important (Joostdevree, 2021):
   1. Share of glass in the façade
   2. Insulation
   3. Airtightness
   4. Thermal bridges
   5. Building orientation
   6. Shape of the building
   7. Shading

   For determining the amount of energy that a building is allowed to consume per m^2 usable floor area, the building envelope to usable floor area ratio is used. For this calculation the following formula is used: Als/Ag whereby Als is the building envelope and Ag is the usable floor area. The maximum energy consumption is different per building function and building type. For stacked houses such as the ones DUWO produces, the maximum energy consumption is 65 in kWh/m^2 usable floor area per year.
2. The second indicator limits the maximum primary fossil energy consumption in kWh/m^2 usable floor area per year. For this indicator the energy need of installations that are related to cooling, heating, hot water and ventilation is determined. The difference between indicator 1 and 2 is that with indicator 2 the system losses are being considered as well. For stacked houses, the maximum amount of primary fossil energy consumption is 50 kWh/m^2 usable floor area per year. The total primary fossil energy is the total energy use of the building minus the amount of renewable energy.
3. The last indicator sets a minimum share of renewable energy. This indicator gives a minimum share of renewable energy that should be used for the energy consumption of the building. According to the NTA 8800 the following energy sources are renewable: solar, geothermal, earth, seasonal thermal storage (WKO), wind, energy from outside air and biomass. Spare heat or cold that is used in city heating is not always considered renewable energy, but under some conditions it is. This renewable energy

share is calculated by dividing the amount of renewable energy by the sum of the renewable energy and the primary fossil energy. For stacked housing, at least 40% of the total energy consumption should be gotten from renewable energy sources.

In addition to BENG, there is the MPG rule which stands for environmental performance buildings (RVO, 2021). The MPG gives an indication of the environmental impact of the used materials in a building and therefore the total sustainability of the building can be determined. An MPG calculation is required for the application of an environmental permit for housing and offices. Because energy performance (BENG) of a building has become more important, also the MPG has become more important to determine the sustainability of the building. This is because measures that are positive for the energy performance can be negative for the MPG and the other way around. For example, better insulation or PV-panels are good for the energy performance, but not good for the MPG. The environmental impact of a material is determined through a life cycle analysis (LCA), which results in environmental cost per unit. The MPG of the building is calculated by adding all environmental costs of all materials. Materials that should be replaced during the building lifetime are also included in the calculation. Furthermore, the MPG calculation considers the application, lifetime, and reuse of materials. Therefore, to get the MPG value, the total environmental cost is divided by the building lifetime and by the gross floor area. Building elements that contribute the most to the MPG score (60-80%) are facades, floors, and installations. In 2021 the MPG has a maximum value of 0.8 €/m^2BVO/year, which will be gradually increased to 0.4 €/m^2BVO/year in 2030 (RVO, 2021).

Furthermore, there is also the TO_{juli} requirement to which new buildings must adhere (RVO, 2022). This rule prescribes a maximum internal heat value and was implemented to reduce the chance of overheating because of the increasingly hot summers in the Netherlands. Due to the BENG 1 indicator, new buildings are being designed as energy efficient as possible by increasing insulation and making the building airtight, which makes that the building retains more heat. This leads to high indoor temperature, which can cause health risks and disturbance for the residents. Mainly direct sunlight through windows has a big effect on overheating and therefore should be reduced as much as possible through the design and the orientation of the building. According to a building evaluation report that Nieman made for DUWO, the following building design aspects have a low or high impact on the TO_{juli} score:

- Building mass : High
- Insulation : Low
- Window size : High
- Building orientation without sunscreens : High
- Building orientation with sunscreens : Low
- Size of window ventilation : High
- Summer night ventilation : High
- Influence resident : High
- Sunscreens : High

The maximum value for TO_{juli} is 1,2, which is automatically calculated via software that is based on the NTA 8800. If it is not possible to stay under this value by optimizing the design and using passive house features (overhangs, small windows, and shutters to reduce the direct sunlight etc.), active cooling can be implemented. If sufficient active cooling is used the TO_{juli} value is automatically set to 0. The downside to using active cooling is that it has a negative effect on the BENG 2 rule, because more energy is needed and on the MPG.

3.3 STAKEHOLDERS

The realisation of the advantages of modular construction and implementation of standardisation, TCO, flexibility, sustainability all depend on the stakeholders that are involved in the construction process. The success of a modular construction approach depends on how well information is shared between the parties involved (Wilson, 2019). Therefore, it is key that before the design begins the responsibilities and scope of work for each stakeholder should be defined. This should be done to prevent potential gabs or overlaps in scope, with which a scope of work checklist can help. In this chapter the role of each stakeholder that is involved in a project will be discussed in relation to modular construction.

Developer

According to Bertram, et al. (2019) realizing the benefits of modular construction will require different stakeholders to make a series of choices. Developers will have to change their thinking from unique projects and opportunities to a productized way of thinking. To do this they will have to identify the segment in their portfolio where volume and repeatability come into play, which can be assigned as the product core that remains consistent across developments. They also should articulate the right design parameters that balance modularization at scale with the freedom to tailor each project. For successful modularization it will be crucial to build a relationship with the modular supplier, which means that they should aim to transition from operating on a project-by-project basis to forming a strategic partnership with involved stakeholders. In this partnership they should try to optimize for manufacturability and make the right trade-offs among quality, cost savings and time savings to eventually reach a standardized but customizable design. Developers can be the catalyst for the transition to modular construction, as they can determine how and by whom their projects are being realized. Because of this they can also benefit a lot from the advantages of modular construction. The early movers can gain significantly when they pocket the cost savings that modular construction gives, until they have to hand in these savings to clients in order to stay competitive (Bertram, Mischke, & Sjödin, 2019). The first step for developers should be to test fully modular construction on an individual small-scale project to gain experience and trust in the supplier. Based on this experience the process can be tweaked to be rolled out and applied to large number of projects. Developers will most likely face many challenges when adopting modular construction, but when modular construction is applied to large scale, the advantages that have been discussed earlier can lead to great benefits for them.

However, social housing organisations such as DUWO don’t always develop student housing themselves. They often use turnkey contracts, which means that developments of new student accommodations are not done within the organisation, but are handed over to other developers. They do this because a project is part of a bigger project, because they don’t have enough developers inhouse or want to reduce risk (Interviewee B1, personal communication, November 25, 2021). Due to these turnkey contracts DUWO sometimes has less influence on the choice between modular and traditional construction.

Investors

For investors modularity is particularly interesting, because it is an opportunity to set itself apart from other investors (Bertram, et al., 2019). They will also overtime have the benefit of reduced market risk due to the repeatability and thus reusability of the design aspects, which will provide investors more confidence in the success of the project because it has already been demonstrated to resonate with the market (Bertram, Mischke, & Sjödin, 2019). Because DUWO could also be seen as a long-term investor, these advantages could be beneficial for DUWO.

Designer

The level of modularity influences the freedom of the designer. This means that when using 3D volumetric elements, which is a high level of modular construction, the design freedom of an architect is limited. Especially when not only the secondary spaces, such as a shower or toilet cell are modularized, but also the primary spaces, such as bedrooms and kitchens. Because of this, the architect can feel that he loses his control over the entire building design and that his role becomes secondary or purely shape focused (Delrue, 1969). This is due to the form of standardisation that 3D modular construction entails, which means that many aspects of the building are already determined. Because of this you would think that architects are not so keen on modular buildings, as this takes away a lot of their work. However, in the design meeting for a modular student accommodation the architect Studioninedots proposed to find a standard module that can be used for all student accommodations in the future.

Modular manufacturer

The main task of the modular manufacturer is of course to produce the building modules that can be used to assemble the building. To be able to start doing this, the design needs to be finished, in which the modular manufacturer will have a significant role to play. Because the manufacturer has all the knowledge about the modular system that he uses, he will be an important consultant to the architect and needs to be involved very early on in the design. Furthermore, quite often the modular manufacturer takes over the role of the contractor in the assembly phase. This is because during assembly of the building very little manual labour is required and because the assembly requires some experience which the modular manufacturer has inhouse.

4 ADVANTAGES AND OBSTRUCTIONS

In this chapter the advantages and obstructions that different stakeholders experience when using modular construction will be discussed. It is important for the uptake of modular construction that the advantages are clear, because this gives stakeholders a reason for choosing modular construction. It is also important for the uptake of modular construction that the obstructions against choosing for modular construction are clear, so that stakeholders can deal with these obstructions.

4.1 ADVANTAGES OF MODULAR CONSTRUCTION

Modular construction has many advantages over traditional construction, which had led to an increased interest in modular construction from different stakeholders. However, to reach the full extent of these advantages, experience, and design for economies of scale are of great importance (Bertram, Mischke, & Sjödin, 2019). This was discovered through a survey that was done in Las Vegas, which shows that there is a big difference between experienced and inexperienced stakeholders when it comes to the perceived and achieved benefits of modular construction (Paliwal, Choi, Bristow, Chatfield, & Lee, 2021). Furthermore, to achieve the full potential of these advantages, the involved stakeholders need to communicate very well, and repetition should be implemented well beyond individual large projects (Bertram, Mischke, & Sjödin, 2019). The below mentioned advantages do not have to be advantages for all stakeholders, for example reduced transportation is not an advantage for a transportation company, because they will have less work in the future. Therefore, the advantages mentioned below are stakeholder specific, and the stakeholders that benefit most will be mentioned. Most of these advantages have been retrieved from literature, but during this research new advantages were discovered through interviews and case studies that have been added to the list.

Decreased construction time

Based on interviewee S1 and literature review, the main incentive for building owners/investors/developers is the increased revenue that can be achieved due to shorter construction time. With 3D modular construction, the construction time of a construction project can be reduced by up to 50% due to the possibility of fast-tracking (Said, Ali, & Alshehri, 2014) (Bertram, et al., 2019). This means that parts of the building can be worked on simultaneously such as the foundation and the 3D modules, which shortens the construction time. Because of this reduced construction time, the building will be sooner ready for the owner to rent out or use themselves. This means that the owner can sooner start earning rent money from the project, which can add up to be a significant sum on a project that would normally take two years to construct. Furthermore, many developers and social housing associations use loans to realise the building over which they have to pay interest. This interest cost starts when the plot is bought and during the construction phase the loan gradually increases until the building is finished, and the full construction price has been loaned. Therefore, a faster construction time will reduce the time that interest has to be paid while no income is gotten, which can add up to a significant amount for large buildings.

Environmental sustainability

An incentive that has been growing in significance in the past several years is the sustainability aspect of modular construction. Sustainability has become more important for nearly all stakeholders because the government has been implementing increasingly strict rules in the building codes about sustainability. 3D modular construction provides the ability of relatively easy reuse of modules and materials (Thai, Ngo, & Uy, 2020). Currently the construction industry is responsible for the consumption of about 40-60% of the total raw materials (Paliwal, Choi, Bristow, Chatfield, & Lee, 2021), which can be greatly reduced in the future when reusing modular buildings. Due to this reusability aspect, the lifecycle cost of a building can be reduced due to the ability to sell building parts when the building is at its end of life. This easy reuse is only possible when no wet connections are used for the connection of the modules, which makes it possible to disassemble the building and retrieve the modules. This is an advantage for project initiators because the reuse of materials has a positive impact on the building price. The possibility to disassemble a building also gives the opportunity to easily, quickly, and inexpensively accommodate change (Slaughter, 2011). This way a building that has become obsolete can be changed to fit another function that is needed. This can improve the value of the building for the owner and reduce disruption and downtime for the occupants. Also, due to modular construction, construction waste can be reduced by up to 70% (Lawson, Ogden, & Bergin, 2012) (Nazir, et al., 2020). Because waste has a high environmental impact and construction processes are responsible for 30-40% of all waste generation, modular construction can make a real difference. This waste is reduced because of the possibility of reuse, which enables disassembly of buildings instead of demolition and because precise ordering is possible in the factory. The reusability aspect of modular construction will become more and more important for all stakeholders as we come closer to 2050 at which point the construction of buildings needs to be a 100% circular (European Union, 2020).

Reduced traditional labour

Modular construction offers a reduced need of traditional trade labour (Pan & Hon, 2020) (Lawson, Ogden, & Goodier, 2014). This is an advantage for the modular manufacturer/contractor because they are currently struggling to find people that want to work for them. Currently 83% of the contractors in the Netherlands experience labour shortages (Cobouw, 2021). This is caused by the fact that more construction workers leave than join. A cause of this is that people these days rather do a less labour-intensive job and don't like to work outside in different kind of weather conditions. Modular construction can solve this by offering a nice indoor work environment. Also, because standardisation of the production process is possible, less skilled workers can be used in the construction process of the 3D modules. This means that a different pool of people can be accessed that normally would not want or be able to join the construction sector (Bertram, et al., 2019). On-site assembly of the modules requires significantly less workers than would have been needed for traditional construction. This together with the increased efficiency and less downtime that can be achieved in the factory will ensure that less construction workers are needed for the construction of a modular building than for a traditional building (Bertram, et al., 2019). On top of this, automation is possible in the factory, which means that robots can do the heavy or repetitive jobs. This is not yet implemented in many factories, because manufacturers don't feel secure for their return on investment due to the low levels of adoption of modular construction (Lacovidou et al. (2021). Once adoption of modular construction increases, more manufacturers will invest in robotic systems that reduce the need for manual labour and can decrease the price of modular construction (Blanco, Mullin, Pandya, Parsons, & Ribeirinho, 2018). An added advantage of automation is that robots can do the heavy physical works while the worker only needs to assist the robot and help it when it gets stuck, which is good for the health of the worker (Blanco et al., 2018).

Cost saving

According to Bertram et al. (2019) cost savings can be as much as 24% using volumetric modules and 17% using panelised systems compared to traditional building. Cost savings are mainly an advantage for project initiators that need to pay for the building, but also for the modular manufacturer. That modular construction can reduce cost was also discovered by (Nazir, et al., 2020) who compared traditional construction against modular construction, which resulted in approximately 30% cost reduction for modular construction. However, Sun et al. (2020) found that due to the increased capital cost and the immature modular market that the cost of a modular building is higher than that of a conventional building. The possibility of construction cost saving is mainly achievable (currently) for buildings that have the highest proportion of labour-intensive activities and the greatest levels of repeatability. This means cost savings cannot always be realized and depend on the country and building function. Later in chapter 6.2.1, the possibility of cost saving will be discussed in more detail based on interviews with modular manufacturers and a comparison of modular and traditional student accommodations.

Building quality

Modular construction offers increased building quality, which can have a significant impact on the performance of the building, resulting in reduced energy use (Bertram, et al., 2019). This is possible due to the tighter tolerances of joints that can be achieved in a factory, resulting in better air tightness and thus better thermal performance (Lawson, Ogden, & Bergin, 2012). Also, the acoustic quality of the building is greatly improved due to the double layer construction (Lawson, Ogden, & Bergin, 2012). The increased building quality is an advantage for the project initiator because they want a good quality building, but also for the user of the building because they experience this increased building quality.

Increased safety

An advantage for the modular manufacturer as well as for the construction workers is that modular construction offers a safer construction process. Modular construction is safer than traditional construction because the construction is mostly taking place in the secure environment of a factory, which reduces the risk of construction accidents (Ferdous, Bai, Ngo, Manalo, & Mendis, 2019). Also, the safety on the construction-site is increased because less hoists are needed, which reduces the chance of something falling on pedestrians as well as on construction workers (Bertram, et al., 2019).

Reduced transportation

Due to modular construction, delivery vehicle visits to the site can be reduced by up to 70% (Lawson, Ogden, & Bergin, 2012). This is because the bulk of the deliveries are moved to the factory, where each visit can be used to deliver more material than could be delivered to the construction-site. According to modular manufacturer van Wijnen (2020), up to 49% less lorries are needed to bring materials to the construction-site when using modular construction. This is very beneficial for inner-city building sites, as there is less disturbance for traffic and neighbouring properties when there are less lorries going to the construction-site.

Disturbance

In combination with the reduced disturbance of less transportation, neighbouring buildings are not affected as much when using modular construction, due to reduced noise and disruptions coupled with a shorter construction time (Lawson, Ogden, & Bergin, 2012). This can be a big advantage for the modular manufacturer/contractor, because sometimes can be very difficult to start building due to complaints of neighbouring residents. If construction causes very minimal disturbance, it is easier to get a permit, which saves a lot of money and time.

Reduced failure cost

According to interviewee B5, S5 and S6 a big advantage of modular construction is the reduced chance of failure, due to standardisation. With traditional construction, for every project the wheel is being reinvented to some extent, because nearly all projects are unique. This uniqueness gives a high chance for failure, meaning extra costs that did not have to be made. Based on a survey from ABN Amro, 61% of all parties that are involved in the construction process estimate that their failure costs are between 2 and 8 precent, and only 34% indicates that their failure costs are below 2 precent (Buijs, Wolf, & Heel, 2019). Modular construction involves standardisation, which means that the same product is made more than once. This has the advantage that the people working at the modular factory can learn from their mistakes and improve the product based on experience. This will not only reduce the failure cost, but also the product will become better.

4.2 OBSTRUCTIONS

Despite the many advantages that modular construction offers, adoption has been low. This is because the construction industry in general is unfamiliar and not confident with implementing modular construction (Bertram, et al., 2019). This is because every stakeholder that is involved in the construction process experiences obstructions that hold them back on using modular construction more frequently. All these obstructions are context specific and do not always have to be there and they can all be solved. Initially the word barriers was used, but barriers sounds like something that cannot be overcome, while most barriers hindering the uptake of modular construction can be overcome. Therefore, the word obstructions has been used in this graduation thesis instead of barriers. In this paragraph these obstructions will be elaborated upon to get an overview of what is hindering the uptake of modular construction. These obstructions are just like the advantages mostly based on literature review, but obstructions that were found during this research through interviews and case studies have been added as well. The obstructions will be grouped in suppliers (architect, modular manufacturer, contractor), buyers (developer, client, investor) and government, because the obstructions for these groups are the same. There are also some general obstructions that apply for all involved stakeholders, which will be discussed first.

Misconceptions

The first obstruction are misconceptions about modular construction that hinder the uptake of modular construction (Jiang, Mao, Hou, Wu, & Tan, 2018) (Lacovidou et al. (2021). Modular buildings are considered to be more structurally vulnerable due to collapses of buildings around the world back in the 60s. For example, the 22-storey prefabricated Ronan Point block collapse in 1968 in East London. These accidents made the durability and structural integrity of prefabricated buildings questionable to the public and created a negative public perception of modular construction (Lacovidou et al. (2021). Modular buildings have however proven to be very safe and reliable in earthquake-prone regions (Mills, Grove, & Egan, 2015). Another obstacle to the take up of modular construction is the public perception that modular construction is a cheap, ugly, poor-quality and an industrialized alternative to traditional construction processes (Jellen, 2015). This is however not the case anymore and as indicated in the advantages of modular construction, it provides an even a better-quality building than with traditional building methods. Also based on interview S1, there are many possibilities of changing the appearance of a modular building, so that you cannot even see the difference between a modular and a traditional building anymore. These misconceptions make that the majority of the construction firms are not fully aware of the advantages of modular construction (Jiang, Mao, Hou, Wu, & Tan, 2018). This in combination with the lack of social acceptance of new construction techniques is a significant challenge. Because of this negative public perception, in recent years, modular construction was rebranded to modern method of construction (Lacovidou et al. (2021).

Lack of collaboration

Furthermore, in the construction sector there is often a lack of collaboration between the different involved parties (client, architect, contractor, manufacturer), which is according to a study done by Sun et al. (2020) the number one obstruction for the uptake of modular construction. Unlike other sectors that accepted innovations very well, the construction sector has historically failed to sustain innovation long enough so that it can harness the benefits of it (Murphy, Perera, & Heaney, 2015). One of the main reasons for this, is the separation of the design and construction stages that is applied in the traditional design-bid-built delivery model. This traditional delivery model is linear, meaning that first the design is made and once the design is finished the contractor is involved, leading to poor communication between stakeholders. Because of this separation, new technology and building methods that are adopted during the design phase struggle to survive during the construction phase. This poor communication also hinders innovation, because innovation is an iterative process, which requires a lot of flexibility and good communication. Modular construction using volumetric units is a relatively new innovation in the building sector and therefore requires flexibility and good communication in the building process. This makes that the traditional delivery model is not suitable for the construction of modular buildings (Wilson, 2019). Better delivery models for modular construction are design/build and integrated project delivery (Wilson, 2019). These delivery methods ensure collaboration and trust through involving the contractor and manufacturer early in the design phase. This will make the design a lot more efficient, as the manufacturer and contractor can give feedback on the design, explain constraints imposed by the module production and give guidance throughout the design process. This also allows for real costing to be performed early in the process so that the design can be steered to be within budget.

4.2.1 BUYERS

Organisational structure

With buyers, the project initiators are meant which buy a product from the suppliers. An obstruction for these buyers is the organisational structure of the firms. This resulted from interviews with different disciplines within DUWO that indicated that the organisational structure is a major obstruction for modular construction to effectively be implemented. This is because DUWO is organised in different branches that are responsible for their own part in the building lifecycle. This means that all branches get some money for performing their own task, but this way every branch mainly has their own interest in mind. For example, the developer wants to build a building within budget, the maintenance branch wants to do maintenance as cost efficient as possible and the finance branch wants all branches to be within budget. This is a great obstruction for implementing total cost of ownership (TCO), which should be looked at when implementing modular construction the right way. This is because many advantages that modular construction can offer are experienced during the exploitation phase of the building. For example, the reusability of modules and materials that is possible with modular construction should be considered in the financial calculations, because this means that the building will have a higher rest value.

Unsuitable building plot

Unsuitable building plot due to the shape can be a practical obstruction for a developer to choose modular construction (Interviewee B1, personal communication, November 25, 2021). With 3D modular construction the design freedom is strongly reduced, due to the standardized nature of modular construction. This means that when the building plot has a shape that does not correspond with the form of the module, often the decision is made to not use modular construction. The main reason for this is that developers want to realize as many square meters as possible, which is only possible if the building follows the contours of the building plot. Related to this, based on personal communication with interviewee B3, 3D modular construction has the disadvantage that the storey hight is a bit higher than with traditional construction. This is because each 3D unit has a floor and a roof and when they are stacked these floors and roofs use quite a bit of space. With traditional construction each storey only has a floor, which means that with modular construction the space of the roof is added to the storey hight. This can be an obstruction for developers, because most of the time a building plot has a maximum building height that is set by the municipality. This means that with modular construction, depending on the maximum building height it is possible that a developer can realise one storey fewer. This can cost the developer a lot of money due to decreased revenue, which makes 3D modular construction not a good option.

No late changes

An obstruction for clients and their teams is that they cannot make late changes to the building design anymore, without major consequences to the building schedule and budget (Lacovidou et al. (2021). Clients will have to get used to this and see the advantages that this can bring them. Normally design can overlap with construction allowing minor modifications to the design of a building during construction. This is not possible with modular construction, because the design needs to be specified very early on in the building process. Late changes will cost more money and may lead to waste generation (Lacovidou et al. (2021). Encouraging clients and their teams to complete their design decisions early in the design process increases the viability of modular construction as well as the resource, time, and cost efficiency levels. It also reduces construction time, construction cost and gives greater certainty on project delivery.

Financial risk

Unwillingness of financial investors to fund prefabricated projects can be an issue (Ferdous, Bai, Ngo, Manalo, & Mendis, 2019). These investors are most likely not familiar with modular building, and therefore see more risks for the project to fail. One of these risks is the manufacturer failing to deliver, which creates risks in the project delivery time, budget, and quality of the building (Lacovidou et al. (2021). This can be resolved if the manufacturer can provide guarantees that they will deliver on time. Also improved education, communication and experience with modular construction is needed for this obstruction to disappear. This in combination with higher upfront cost at the design and prefabrication stage, due to a more detailed design at the beginning of the project is a problem (Jiang, Mao, Hou, Wu, & Tan, 2018). Furthermore, modular construction can bring the risk of a modular manufacturer going bankrupt in the middle of the production process. Normally another contractor can finish the job, but modular construction is usually very specific to the modular manufacturer, and it is not easily possible to find another manufacturer that can continue with the work (Nazir, et al., 2020).

4.2.2 SUPPLIERS

High initial capital

The suppliers are the parties that supply the buyers with modular buildings. A obstruction for the modular manufacturer is that a factory requires very high initial capital (50-100 million) to set up a manufacturing plant for the production of the modules (Bertram, et al., 2019) (Ferdous, Bai, Ngo, Manalo, & Mendis, 2019). Due to the still low demand for modular construction and uncertainty about the future demand, potential new manufacturers are reluctant to put this big of an investment in a modular factory, because they feel insecure about their return on investment (Lacovidou et al. (2021). The lack of modular factories is an obstruction for the uptake of modular construction.

Distance from the factory to the construction site

Because of the low uptake of modular construction and the lack of modular factories, the average distance between the construction-site and the factory can be quite big. This distance is an obstruction, because if the distance is too big the transportation cost will be too much and the project will not be feasible (Paliwal, Choi, Bristow, Chatfield, & Lee, 2021). Due to the just-in-time delivery that is needed on-site, close coordination is need among the manufacturing, transportation, management and assembly operations (Hsu, Aurisicchio, & Angeloudis, 2019). This means that it is very important to optimise time-critical logistic systems and to intensively manage them. When the distance between the construction-site and the modular factory decreases, so will also the transportation cost and the risk for delay.

Lack of design guidelines

There is a lack of design guidelines for modular construction, which makes it difficult for designers to design the building efficiently for the application of modular construction (Ferdous, Bai, Ngo, Manalo, & Mendis, 2019). These design guidelines are of great importance for the success of modular construction because the design stage determines up to 80% of building costs. For off-site construction to be a success a highly detailed design is needed very early on in the project, the construction process requires a different infrastructure, and the effect of geometric inaccuracies and installation must be considered. I noticed this myself when building at the SUM team, as we experienced some delays due to building aspects that were not thought of during the design, which you should try to avoid when industrialising the building process. The design team may also need to take on different responsibilities, as the design should consider the manufacturing process and transportation, which were traditionally considered the responsibility of the contractor. Digital technologies such as BIM are essential to make a detailed design that is a one-to-one copy of the building to be built to minimise failure and mistakes at the construction-site (Wilson, 2019). To maximize the efficiency of the design, the architects should produce custom designs that use a range of standardized components. Based on interviews however, the developer should contact the modular manufacturer first and after that the architect. This will however be discussed later in this report in more detail in chapter 6.2.1.5.

4.2.3 GOVERNMENT

Lack of support

Lack of government support is an obstruction for the uptake of modular construction (Sun, et al., 2020). To make sure that modularity is being used on large scale and that the most advantages in the field of sustainability are being realised the government should intervene. The government can do this by switching from an incentive policy to mandatory policies, that will force stakeholders to use modular construction. Examples of these mandatory policies are standardizing modular connection systems that enable reuse and interchangeability and setting a minimum amount of modular construction that should be used. For stimulating reusability of modular elements, sector wide agreements should be made about making standards, which the government can play a role in (de Bruijn, 2021).

5 CURRENT PERFORMANCE

In this chapter the current performance of three modular buildings and one traditional building will be measured. This performance measurement will serve as an indication of which aspects of modular construction for student accommodations should be changed to increase the performance of modular construction (which will be discussed in the next chapter).

5.1 PERFORMANCE DEFINITION

In the main question the term performance has a central place, because through a performance measurement can be determined what needs to be improved to make the implementation of modular construction more efficient. Therefore, in this sub-chapter attention will be given to what performance is and how it can be measured, with the purpose to use this knowledge to measure the performance of modular student accommodations made by DUWO. According to Hensel (2013) the concept of performance started in the humanities and social sciences, which later also took shape in arts, architecture, and science in general. It started in the 1940s and 1950s with an intellectual movement known as the performative turn. This movement theorised performance as a social and cultural element, meaning that performance is dependent on the culture and preferences of people. Lebas (1995) agreed with this definition of performance as he defined it as the capability to meet certain objectives, however due to the subjectivity of objectives there is no clear definition of what performance exactly is. This is because it depends on what managers, organisations or society think is important to measure to timely achieve the stated objectives. Therefore, to determine what is important to measure, the following two questions need to be answered: “why do we want to measure?” and “what do we want to measure?”.

Why do we want to measure?

According to (Behn, 2003) performance measurement is not an end in itself. The reason for managers to measure performance is because they find it helpful in achieving eight specific managerial purposes. These managerial purposes are the following: evaluate, control, budget, motivate, promote, celebrate, learn, and improve. Despite that all these purposes have a different focus, they all have the goal to foster improvement. Because they have a different focus, there is no single performance measure that can be used for all eight purposes (Kravchuk & Schack, 1996). Therefore, managers need to think about which managerial purpose they have for wanting to do a performance measurement, because only then it is possible to select measures with the characteristics necessary to help achieve the purpose. Below, the eight managerial purposes from (Behn, 2003) are explained in more detail:

1. To evaluate: How well is something performing?
   This is the most common reason to do a performance measurement. Performance is measured to evaluate something, just to know whether thinks are worsening or improving.
2. To control: how can managers ensure their subordinates are doing the right thing?
   Managers seek to control their employees by measuring their performance. They do this by establishing performance standards to which the employees must adhere. The control of managers depends on measurements.
3. To Budget: on what programs, people, or projects should an organisation spend money?
   Performance budgeting, performance-based budgeting and results-oriented budgeting are common names given to the use of performance measurement in the budgetary process. Performance measurement can help with making budget allocations by considering historical data in the annual budget request and by allocating budget based on performance criteria.
4. To Motivate: how can managers motivate employees, stakeholders, collaborators, and citizens to do the things necessary to improve performance?

Managers may use performance measurement to learn how to perform better. Once they know how to perform better, they establish performance goals so that people will perform better to reach these goals/targets.

5. To Promote: how can managers convince superiors that they are doing a good job?
   Managers need to validate success to superiors by showing results, which can be done by using performance measurement.
6. To Celebrate: what accomplishments are worthy of the important organizational ritual of celebrating success?
   To give people a sense of their individual and collective relevance and to motivate them for further efforts, all organisations need to celebrate their accomplishments. Through performance measurement can be measured when something can be celebrated.
7. To Learn: why is what working or not working?
   Performance measurement can be used to learn based on what is working and what is not. Therefore, however it is needed to go a bit deeper than just the data and determine the reason for something to perform bad or good.
8. To Improve: what exactly should be done different to improve performance?
   The fundamental purpose of performance information is to make improvements. This cannot be done by just measurement alone, but it can be done through learning from the measurement.

What do we want to measure?

Once the purpose of the measurement is clear it is needed to determine what performance measures are appropriate for which purpose (Behn, 2003). The manager needs to determine the right performance measure for the purpose by checking if the measure possesses the characteristics required for the purpose. Performance measures can be grouped in two types, which are input and output measures. Output measures can however be split in outcome and output as is elaborated upon below:

1. Output measures: output is what you created at the end of a process, they do not address the value or impact of the product or services for the client (Measurementrecourcesco, 2014). Examples of output measures are: people served, number of lettable houses produced, permits issued etc.
2. Outcome measures: The level of achievement that occurred because of the product or services that an organisation provided (Measurementrecourcesco, 2014). Only with outcome measures, managers can answer the effectiveness question: did the organisation achieve the results it set out to produce (Behn, 2003)? Examples of outcome measures are: improved student satisfaction, product affordability, innovation, etc.
3. Input measures: also called efficiency measures, which measure the input that was needed for the output and outcome (Behn, 2003). Examples of input measures are: hours spent, number of employees deployed, money spent on equipment etc.

As indicated before, every purpose to measure requires a different approach. This means that a manager must choose which performance measure type or type combination is suitable for the purpose. In the text below an overview can be seen of suitable performance measures per purpose that are adapted from (Behn, 2003):

1. To evaluate:
   Evaluation requires a comparison between the measured data and some standard, because without this standard it is impossible to determine if something is performing well or poorly. This standard can come from past performance, from performance of similar agencies, from a professional or industry standard or from political expectations. When evaluating, the focus is on the measurement of outcomes, however also input and output measures are necessary. The outcome measures can answer

if the organisation was effective in reaching their goals and the input measures can answer if the result was achieved in a cost-effective way.

2. To control:
   For controlling the behaviour of employees, the manager needs input requirements. They do this by measuring the behaviour of employees and then compare this with a standard to see how well they performed.
3. To budget:
   To use performance measures for budgeting purposes, measures that describe the efficiency of various activities are needed. Based on budgetary priorities, managers can use efficiency measures to suggest in which activities should be invested and how much. To do this, managers need outcome, output, and input measures.
4. To motivate:
   To motivate people, managers need output measures. Organizations do not produce outcomes and the employees do not have an influence on the outcomes. Managers cannot motivate people to do something that they cannot do, therefore the focus should be on output measures.
5. To promote:
   To show that a company is effective and efficient, managers need measures that are easily understood and which superiors care about. This differs per situation and can be input, output, or outcome measures.
6. To celebrate:
   To celebrate something the manager first needs to set a performance target. This can be the same target that has been used to motivate, but when the target is achieved it is time for celebration.
7. To learn:
   To learn, managers need a large number and wide variety of measures that provide detailed information on various operations of the organisation. Often benchmarking is used for this, with the goal to answer what are we doing well/not so well and what do we need to change to improve what is not so well. The measured services, products and practices are benchmarked against similar measurements of processes that are recognized as the best.
8. To improve:
   To increase performance, managers need to understand how they can influence the behaviour of employees that produce the output and customers/users that produce the outcomes. Therefore, managers need to know what is going on inside their entire operational organisation to figure out how the inputs, environment and operations can cause improvements in the outputs and outcomes. Measures are needed that show how the activities of the manager influence the behaviour of all people whose actions affect the outputs and outcomes.

Now that it is clear what performance measure types are used for what purpose, we need to look deeper at what exactly should be measured. To be able to say something about the performance of an organisation it is needed to know what the organisation is supposed to accomplish. Therefore, according to Kravchuk and Schack (1996) performance measurement must begin with a clear understanding of the policy objectives and goal of a company. To be able to measure and monitor the objectives of an organisation, these objectives are broken down in key performance indicators (KPI) (Kaplan, n.d.). Traditionally in early historical times net income was the only KPI on which companies focused, but there are a lot more KPI's such as: reducing environmental impact, establishing brand awareness, improving human resources etc. These KPI's consist again out of different performance elements (Lebas, 1995), for example the main objective net income is the result of many different performance elements such as: customer satisfaction, quality, delivery, innovativeness, flexibility, and cost.

These performance elements again can be divided in different performance elements, for example customer satisfaction can be divided in: availability, usage value, product design etc. This shows that there are many different performance elements that can be measured to evaluate how well something is performing in relation to the main objectives. Based on the purpose of measurement, it is the task of a performance evaluator (manager) to choose which objectives are important and to choose which performance elements should be measured. All these measurements require a baseline/standard to compare the measured data against, so that conclusions can be drawn about the performance. This baseline can be an historical record, information from similar organisations or an explicit performance target established by the manager.

In the paragraphs that follow the performance objectives of different scales within the built environment will be determined. First the objectives of the entire built environment will be examined, after which we will zoom in on student accommodations in general, and lastly the focus will be on the student housing association DUWO. Doing this will provide a broad view of objectives from all stakeholders and not only from DUWO. These objectives will later be used to evaluate the performance of buildings from DUWO, which will be the study case of this research.

5.2 BUILT ENVIRONMENT

The built environment consists out of several stakeholders that all have their own responsibility during the entire building lifetime from cradle to grave. These different stakeholders are responsible for a part of the building process, which means that they all have their own objectives that they want to realise. They have to work together to construct-, maintain- and operate the building. The objectives of all these stakeholders are influenced and shaped by the market and through regulations. Every party wants to incorporate their own objectives into the building and therefore it is useful to look at the objectives of every stakeholder to be able to determine the main objectives from the entire built environment. These stakeholders can be divided in buyers, suppliers, and the government, which will be discussed below.

buyers

The buyer group can also be called clients of the suppliers. There are three types of clients: client that builds to sell (developers), client that builds for own use (client), and a client that builds to rent out (investor). The client can be considered as the most important stakeholder in the building process, because he has the most influence and interest in the project. Therefore, the objectives of the client are of great importance. The client’s reason to build has an impact on their main objectives which should be represented in the building. Clients that want to use the building after construction generally have more of a focus on the entire life of the building and not only on the construction phase. Clients that build to sell have less of an interest in looking at the entire building lifetime, because it does benefit them not as much. When it comes to realising the physical building the main objectives for all client types are that the entire building is produced to specification (program of requirements), within budget and on time (Richards, Bowen, Root, & Akintoye, 2022). In these objectives the golden triangle of time, cost and quality can be seen as a good indicator of project success. For the client that does not want to sell the building after realisation, the exploitation phase is also important to consider. This client wants the cost of operating and maintaining the building to be as low as possible, therefore, energy performance, ease of maintenance and maintenance cost are important objectives as well. These criteria can be measured and controlled quite well, because they can be clearly defined at the beginning of the project. There are however also subjective criteria that relate to aesthetics, user satisfaction, value for money, etc. These subjective values are a lot harder to incorporate in a building design because they are hard to define and differ per person.

If the construction client is not the user, generally the user has the least amount of influence in the project. Despite that, according to Kim, Cha & Kim (2016) involving users, their preferences, and knowledge in architectural, engineering and construction projects is gaining importance. This is because it is recognized that there are gabs between the demand from users and the product designed by architects. To involve the user in the design various methods can be used such as: post-occupancy evaluation (POE), quality function deployment (QFD), and ergonomic design. Although user involvement is used more often, the parties mentioned above still have the final say and can easily overrule the user. Important performance categories for users are according to (McGrath & Horton, 2011): thermal comfort, visual comfort, acoustic comfort, indoor air quality and safety. As also written above for the client that exploits the building after realisation, energy performance and ease of maintenance are also important objectives of the user.

Suppliers

Contractors, architects, and advisors are the stakeholders that realise the building for the client and can therefore be called suppliers. Their main objective is to realise a profit from the work, which can be seen in the fact that with big construction companies the director's compensation is aligned with the company's stock price (Puzder, 2021). These producers realise this objective by meeting the requirements of the client.

For a contractor, how he achieves this depends on the delivery model that is used for the project. When a traditional or design-build model is used the contractor is only responsible for the delivery of the building. This means that he achieves his objective by satisfying the client through delivering a building that is produced to specification, within budget and on time. This shows that using this delivery model, the objective of the contractor is aligned with that of the client that builds to sell. When a design-built-finance-maintain-operate contract is used, the contractor is not only responsible for the delivery of the building, but he will stay responsible for all aspects of the building for a set duration. This means that it is in the best interest of the contractor to also consider maintenance and operation of the building. To take operation and maintenance in consideration, energy performance and ease of maintenance become important objectives for the contractor. Furthermore, he needs to comply with building regulations from the government such as sustainability, safety, building codes, energy efficiency etc. To achieve this, the general contractor needs to make a schedule for the building construction process, lead and supervise the sub-contractors, execute the work, and inspect the construction work.

The architect meets the requirements of the client by making a design that is according to the program of requirements from the client. The architect does have less say in the project than the client, but he can have a big influence on how the requirements of the client and municipality are implemented in the building. The architect does also have a lot of interest in the project as his success has a positive effect on his reputation, and his failure a negative effect. Furthermore, according to many academic curricula and syllabi, architecture also includes a social aspect, because they shape the built environment. This social aspect represents itself in finding a good balance between shape, structure, and function, while considering the urban context.

Municipality/government

The municipality and government have the most amount of influence in a project because they can enforce rules on the building sector. The municipality performs tasks that are of importance for its inhabitants (Rijksoverheid, n.d.). An important task of the municipality that is related to the build environment is making sure there is enough living space for inhabitants. The municipality does this by making zoning plans in which they indicate what is allowed to happen with the soil and how this should roughly look like. This way they keep the expansion of the municipality in control with the goal to keep a good balance between functions and the green to build area ratio and to keep the city aesthetically coherent. Another task of the municipality is to supervise the construction process. To do this they check the building plans and give a building permit if the plans correspond with the rules from the zoning plan and the building codes. Because a building should be safe for the users and the surrounding, the government has made building codes in which there are rules about safety, health, usability, energy performance and the environment (Rijksoverheid, 2021c). These rules in the building code are mandatory for every building and therefore should be considered as an important objective for the building industry.

Conclusion

Depending on the reason that a stakeholder is involved in the construction/exploitation process, the objectives of stakeholders vary. There is a lot of overlap between objectives of stakeholders, but a clear distinction can be made between stakeholders that build or that exploit the building. For stakeholders that realise buildings, **construction speed**, **construction cost** and the realisation of a building according to **specification** are important. Depending on the building function, these building specifications can differ for every project. These specifications of the client are documented in a brief, which should be as detailed as possible. Examples of requirements that are in the brief are: overall sizes of spaces, whole life costs, flexibility, energy performance standards, lifespan, and maintenance requirements etc. Because every project brief is different, it is not possible to define important objectives from the brief for the entire built environment. The only thing that can be said for the entire built environment is that it is an important objective that the building needs to be realised according to specification from the brief. For the parties that exploit the building **maintenance cost** and **user satisfaction** are important, because this has an effect on the building exploitation cost and the net building income. For users of the building **energy performance**, **thermal comfort**, **visual comfort**, **acoustic comfort**, **indoor air quality** and **safety** are important objectives. There are also enforcing objectives that come from the government that serve a social goal. These objectives are mainly aimed at the wellbeing and health of building users and on protecting nature and animals that don't have a say in the building process. For the most part the objectives that are aimed at the building user correspond with the objectives of the user. The objectives that are added that every stakeholder should take into consideration (even though they have no to very little direct benefit for the stakeholders) are related to the **environment**. Lastly, for all involved stakeholders **innovation** is beneficial, because through innovation the building process can be made smarter, better and cheaper. Despite the advantages of innovation, the building sector only invests barely 1% of their turnover in research and development (Cobouw, 2020). Despite that not much is invested in innovation nearly all big stakeholders such as contractors (VolkerWessels, Bam, DuraVermeer), architects (mvrdv, OMA, UNstudio) and developers (VORM, BPD, Heijmans) promote themselves with writing about innovation on their websites. Therefore, innovation can also be considered as an important objective for stakeholders in the building sector.

5.3 STUDENT ACCOMMODATION

When someone refers to student accommodations in the Netherlands, they most likely mean rental rooms in which student live. There are generally speaking two ways students can get a room, which is by renting from a social student housing association or by renting from the private sector. The latter often means that the room is more expensive, but students don't have a choice due to the student housing shortage. This limited choice also effects the requirements that students have for a room, because they currently just have one main objective, which is to have a place to live. This means that they put their other objectives aside just to have a room, but when looking at the performance of student accommodations these other objectives should be considered as well. Students are different users than the average user in the built environment and therefore the objectives of the average user can differ from student's objectives. For students socialising is very important, especially when they just start studying and they need to make new friends. Therefore, they want to live close to the university, so that they can easily meet with classmates and friends. This was discovered trough a post occupancy evaluation of a student building, in which most students indicated that the main reason for choosing the building was due to its location (McGrath & Horton, 2011). This post occupancy evaluation on the other hand showed that for students the building design and the construction of the building are not important in their decision on choosing a home. Of course, students also have requirements for the physical building as they use their room for everything that they do, from studying to sleeping and from watching movies to having friends over. Therefore, according to (Sannie-anibire & Hassanain, 2016) the **functionality**, **comfort** and **safety** of a room are very important objectives, because room quality has a direct connection with the performance of students. In relation to room quality and the fact that students use their room for all kinds of activities, room size is also considered to be an important objective of students (Boogert, 2018). Often in post occupancy evaluations students are dissatisfied with the intrusive noise from outside or from neighbouring rooms (Woo, 2017). This problem is in most cases rooted in the fact that students make quite a bit of noise, which also showed in the fact that in the post occupancy evaluation only 15% of the students thought the excessive noise was due to the building structure (McGrath & Horton, 2011). Furthermore, affordability of student rooms is of great importance for our social infrastructure of higher education (Eurostudent, 2015). This is because students who do have no financial means to rent a room, would otherwise be excluded from access to higher education. Therefore, the affordability of student rooms is an important objective for the student as well as for our social infrastructure (Boogert, 2018).

Another difference between the built environment and student accommodations is that students rent a room and for the majority don't buy a room. This means that the client is different in most cases for student accommodations because the client is in most cases not the user. The total amount of student rooms in the Netherlands is 387.300, of which 46% is provided by private parties and 41% is provided by student housing associations (Rijksoverheid, 2021b). Especially with private parties, the students have not much influence in how the room should look like, because students don't have much money and therefore the room needs to be constructed as cheap as possible. The part of the student houses that is produced by social housing associations has generally a greater focus on providing a quality room for the student, because the social housing associations are not allowed to make a profit and therefore their core objective is providing housing for students. DUWO checks student preferences by doing student satisfaction surveys per building and quick surveys that can be specific for a part or element of the building. This way they can get feedback on the current buildings and incorporate this feedback in new buildings.

For the rest of the stakeholders such as the municipality, contractor, and architect the objectives are the same as for the entire built environment. The architect and contractor both want to realize the objectives of the client, while making a profit and the municipality has the same objectives for all buildings.

5.4 DUWO

DUWO as an organisation can be seen as a client that builds student accommodations to rent out to students. This means that they will stay the owner of the building for the entire lifetime of the building. They also facilitate operate and maintain most buildings inhouse and therefore the energy performance and maintenance cost are of importance to DUWO. Because DUWO is a social housing association that cannot earn a profit on the buildings they are different than most clients in the fact that the focus is on providing qualitative and affordable student housing. The main mission of DUWO is: "Fight for honest student accommodations in which affordability, availability, safety and quality of student accommodations form the basis". Based on this main mission DUWO has formulated their main objectives. These main objectives can be found in the “ondernemingsplan” in which DUWO elaborated on their goals for 2022-2025. In the text below, the goals from the onderneminsplan will be discussed, including how the goals are reached and if they deviate from the goals from the entire built environment. This information was gathered through interviews with different employees within DUWO.

1. **The customer should be satisfied, and the business should revolve around the student**
   With this goal DUWO means that they want to take the input from the user into consideration when designing a new building. They gather this input from the users through surveys and student satisfaction evaluations that are done per building. This feedback can be implemented in new buildings. DUWO differs in this aspect from other similar stakeholders such as commercial developers. For developers earning a profit is the most important goal and therefore they can sacrifice user comfort and quality.
2. **Expand the current student housing supply;**
   In interviews, most employees of DUWO even said that realising as many student accommodations as possible was their main goal. This DUWO objective relates to the overall objective of construction speed because this influences the amount of expansion that DUWO can do. Despite this, construction speed is not very much important for the development branch of DUWO, because they do not have to consider the interest on their loans during the construction phase. Only after the building has been realised this interest will have to be considered in the financial exploitation calculations. Even though the developers don’t have to take this interest into account, a longer construction phase will cost DUWO a lot of money considering they are paying an average of 3% interest on loans. Because the development branch of DUWO is responsible for the building phase and currently there is not much stimulance to deliver a building faster, the goal of DUWO to expand the current student housing supply could be achieved more efficiently. This could for example be achieved through modular construction, which is up to 40% faster than traditional construction.
3. **Make sure the student housing is affordable;**
   For DUWO this means that the rent for a student room is at the “kwaliteitskortingsgrens”, or the “eerste-aftoppingsgrens”. The reason for this is explained in the text that follows and is adapted from woonbond (2022). To determine the rent that a student needs to pay you first need to look at the “basishuur”. This “basishuur” is what students need to pay for their room themselves, which is at the minimum 237,62 euro, but it scales to income. The gap between the “kwaliteitskortingsgrens” (which is 442,46 euro) and the “basishuur” is completely covered by the government in the form of a rent subsidy. Students that are younger than 23 can only get rent subsidy until the “kwaliteitskortingsgrens” and therefore DUWO tries to make as many rooms that are under the “kwaliteitskortingsgrens” as possible. Students that are older than 23 can also get an extra subsidy that reimburses 65% of the rent price that is above the “kwaliteitskortingsgrens” until the “eerste-aftoppingsgrens”, which is 633,25 euro. The goal of DUWO is to have at least 80% of their rooms under the “kwaliteitskortingsgrens”. Therefore, DUWO reaches the goal of affordability for the users very well and a lot better than public parties that rent out student rooms. On top of this rent price there are also service costs that the student needs to pay, which include energy use and cleaning costs of the building. DUWO wants to keep these as low as possible, but there is no set goal for the height of the service costs. These service costs are mainly lowered due to sustainability measures that need to be taken, which positively affect the energy use of the building.
4. **Speed up the realisation of sustainable buildings to reach the goal of the EU to be 100% energy neutral by 2050;**
   The government has set the goal to be a 100% energy neutral by 2050 and therefore companies need to follow this goal. The government has already enforced rules for making the built environment more environmentally friendly through the building codes, such as BENG and MPG. This sustainability is an

important objective of the government, but for a lot of stakeholders this is not so important. These stakeholders would not make the building more sustainable than necessary, because it costs more than they can get in return. Based on interviews with the development department of DUWO, this is also the case for DUWO. This is contrary to the goal that was written down in the policy document for DUWO in which they state that they want to speed up the realisation of sustainable buildings to reach the goal of 2050. A big reason for this is that extra sustainability also raises the initial cost of a building, which they cannot charge the student for. This is because they have to follow the maximum rent price that they can ask that is based on a point system and sustainability is not part of that point system. Furthermore, they want to keep making affordable student rooms and therefore they cannot exceed the “kwaliteitskortingsgrens” or the “eerste aftoppingsgrens”.

5. **Innovative and efficient working;**
   As indicated in the objectives of the built environment, most stakeholders want to innovate to optimize the processes, so that they become better, more efficient, and ultimately cheaper. DUWO also has the goal to innovate but based on interviews they do not have the goal to innovate in the process of developing buildings, but in the user experience by implementing digitisation. They do however improve construction processes, by organising meetings to discuss how BENG should be effectively implemented, and they have a workshop about modular construction.
6. **Give special attention to the wellbeing of the student;**
   This objective aligns with the objective of users that want comfort and safety. DUWO provides this through large windows, control over the heating/cooling system and noise reduction of the building that corresponds with the building code. Furthermore, DUWO provides safety by using multiple layers of lockable doors in the building and through enough lighting in dark places. DUWO also takes care of the wellbeing of students by providing common rooms in which students can socialise, which is especially important during corona times. The expectation is that hybrid studying will continue after corona is over, which means that students will be more at home and therefore they will want to socialise more at home. Therefore, DUWO has developed a new living concept called the “sting”, in which students have their own room with bathroom and kitchen, but there is also a living room in which students can socialise.
7. **Maintain the financial health of the organisation;**
   With the new sustainability rules and increased material and labour costs DUWO is finding it harder to realise new buildings that can be rented out for affordable prices. Therefore, building cost is a very important objective for DUWO. They are trying to decrease this cost by removing elements that are not perse necessary for a good functioning building. DUWO is responsible for the entire building life of the building, which means that they have to take care of operation of the building, the maintenance and eventually the demolition of the building. The operation costs are covered by the students of the building that pay service costs. The maintenance of the building however, DUWO needs to pay themselves and is paid from the income from the rent. Therefore, to maintain the financial health of DUWO it is important that during the building design, maintenance is already considered. DUWO works with different branches that are responsible for their own branch and all these branches get their own budget. This causes that every branch considers its own branch, which makes that total cost of ownership is not well incorporated into the design. This can be seen in the fact that developers are so focused on reducing the initial price that reduction of maintenance costs are considered less. The clear division of tasks and responsibilities have also been recognised in other social housing corporations as a problem for effective development (Kuij van der, 2014). Furthermore, the demolition of the building is not considered in the design, and therefore according to interviewee B7, in the financial calculations the building is only worth 5000 euro per room after 50 years of exploitation. This 5000 euro is even less

than the actual ground price which is around 12.000 euro, but this difference is reserved for demolishing the building.

Now that the goals of DUWO are clear and we know where DUWO deviates from the average client, the following can be concluded:

1. DUWO is a social student housing association that is there for social purposes and not for earning a profit. In this aspect DUWO is different than most clients in de built environment, because most private sector clients have a focus on profits. For DUWO it is important to keep performing their main mission to realise affordable, available, safe, and qualitative student accommodations and therefore it is important to stay financially healthy.
2. A major goal of DUWO is to realise affordable student accommodations. This differs from most other clients that build to rent out. This makes it for DUWO extra hard to innovate, because there is not that much money left over that can be spent on innovation. The same is true for sustainability, which is not important enough to exceed the required sustainability requirements that are imposed by the government. This is true for most stakeholders in the built environment that have to pay for these sustainability upgrades. As long as extra sustainability benefits have a negative impact on profit or that it endangers the affordability of the student rooms for DUWO, stakeholders will not make the building more sustainable than necessary.
3. As described before, there are clients that build to sell or build to exploit. DUWO can be considered as both clients in one, because there is a clear separation between departments in the way they interact, their responsibilities and their budgets. This causes that the developers within DUWO function as clients that build to sell, meaning that they do not consider total cost of ownership until the other client part that exploits says so. This is not in the best interest of DUWO, because DUWO as an organisation exploits the buildings, which becomes more expensive this way. DUWO tries to combine the wishes of the development side of DUWO and the exploitation side in one standard program of requirements.
4. This separation of departments within DUWO also influences the objective of building speed, which is for most stakeholders in the built environment very important. For DUWO as an organisation building speed should also be very important, because if the building speed is increased, they can reduce the interest cost on their building loan during construction and they can sooner get rent income. Despite this, DUWO doesn't pressure the development branch to increase the building speed, because no interest on loans has to be included in the building cost. This means that in practice DUWO doesn't see building speed as an important objective, which is contrary to the objective to realise as many student houses as possible. This also doesn't stroke with the objective of the entire built environment, whereby building speed is important for all stakeholders.
5. For DUWO student satisfaction and wellbeing is very important. Even though involving users, their preferences, and knowledge in buildings is getting more important for stakeholders, it still is not done that much. DUWO considers the users of their buildings very important and therefore it is important to check for user preferences and incorporate them in the buildings. DUWO does this through yearly student satisfaction evaluations and building surveys.

5.5 KPI'S

In this chapter the key performance indicators (KPI's) that will be used to analyse and measure the performance will be determined. To do this it is important to start with the reason for wanting to do a performance measurement. Based on this reason, the performance measurement type can be chosen. This measurement type together with the objectives determined in the previous paragraphs dictate the choice for KPI's. For every

KPI a goal needs to be determined, which is based on eighter goals from DUWO which come from the "ondernemingsplan" from DUWO or on goals from the entire built environment. These goals are going to be used to evaluate three modular student accommodations that are made by DUWO.

Reason for measuring performance

The reason for wanting to measure the performance of modular student accommodations is to evaluate. This evaluation will show what is going well and not so well compared to the goal that has been established. This evaluation can be used to learn with the ultimate goal to improve the modular construction process. Because evaluation, learning and improving is important, the measurement types that will be used are outcome, output and input measures, which can be seen in table 4.

Important objectives

Based on the previous paragraph's objectives have been defined in table 4, which are important for DUWO as well as for the entire built environment. To measure these objectives different KPI's have been defined to which a goal can be coupled. The goals are based on goals of DUWO, but also of the entire built environment. The choice to not only look at the objectives and goals of DUWO has been made because on some aspects the goals of DUWO lack a bit in relation to what is good for DUWO and good for the environment.

table 4: Objective, KPI and Goal

Objective	KPI	Measurement type	Goal
Financial health	Building speed	Outcome	There is no definable goal for building speed, but the building should be constructed as fast as possible. This saves interest payments and ensures quicker rent income
	Construction cost	Input	Construction costs are defined based on rentability calculations, so they are hard to define here. Generally, the lower the better
	Maintenance cost	Input	DUWO has the goal to spent €501 on periodic maintenance per year per unit and €207 on non-periodic maintenance
Sustainability	Insulation value	Outcome	The insulation values are according to the building codes 3,7 for the floor, 4,7 for the walls and 6,3 for the roof.
	Heating and cooling energy use	Input	The current BENG rule is 65kWh/m2, but this should be lowered as much as possible
	Renewable energy share	Output	The BENG standard is 40%, but DUWO should try to make this as close to 100% as possible
	Building lifetime	Output	Currently the building standard is 50 years for DUWO and the built environment
	Possibility of reuse	Outcome	There is no definable goal yet, but DUWO should aim at making buildings as reusable as possible
Affordability	Service cost	Outcome	There is no definable goal, but they should be as low as possible
	Rent price	Outcome	The rent price should be for 80% of the total building stock lower than the “kwaliteitskortingsgrens” which is applicable for students younger than 23 and the rest should be lower than the “eerste-aftoppingsgrens”
Student satisfaction	Thermal comfort	Outcome	The thermal comfort should be good for all students
	Acoustic comfort	Outcome	The acoustic comfort should be good for all students
	Ease of maintenance	Outcome	The ease of maintenance should be good for all students
	Room size	Output	The minimum single room size is 18m2
Student wellbeing	Fire safety	Outcome	The fire safety of the building should be good
	Size of common rooms	Output	DUWO has set the goal that all buildings should at least have 50m2 of common rooms and 0.5m2 per room

5.6 BUILDING DATA

In this chapter building information will be gathered for three modular buildings and one traditional building. This information will be filled in per KPI in a comparison table in which the buildings can be compared with each other. First the four buildings will be introduced after which the comparison table can be seen.

5.6.1 HILDEBRANDPAD (LEIDEN)


figure 6: Hildebrandpad retrieved from DUWO

The construction of these two modular buildings started in December 2010. The first module was placed in March 2011. Two weeks later the highest point of one building was already reached, and the buildings were delivered in two phases. The first building was delivered in October 2011 and the second building in February 2012. This means that it took about 15 months to construct both buildings from foundation to interior finish. The two buildings together are good for 504 single room student apartments that all have their own bathroom and kitchen. The rooms have a total room surface of 28.5m^2 including bathroom and technical space (figure 7). The building has a total of 7 storeys that are placed on top of a ground floor that houses 857m^2 of commercial space and spaces for bikes, motorbikes, garbage and washing machines. The total building price of the two buildings was €32.300.00 including €3.500.000 for the ground. The buildings are designed by architect Claus and Kaan and realised by the modular manufacturer Ursem.

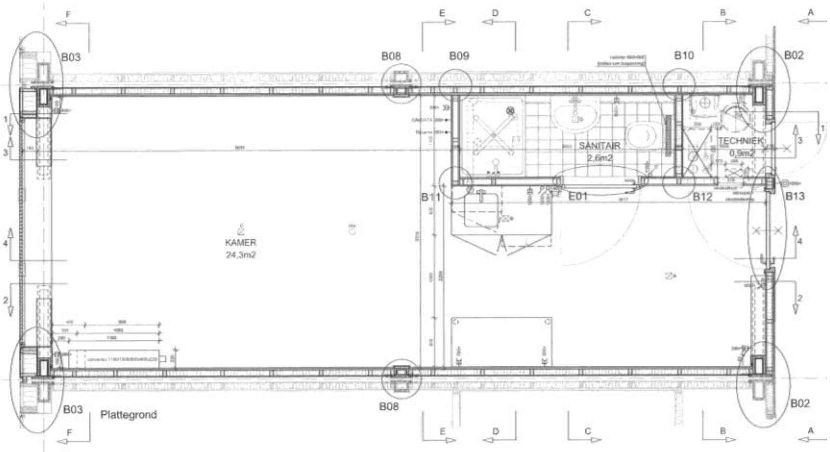


figure 7: Student room floor plan Hildebrandpad

The building uses a modular building system that uses a concrete floor with a steel frame and a wooden infill for the walls (see figure 8). The modules that are used are 3D room sized modules, which have been produced in a factory and come completely finished with interior finishes. This system can be stacked until eight floors without solid connections, but if you go taller than eight floors a substructure or different modular system is needed.

This building experienced an overheating problem in summer due to the black colour of the building and the big windows (see figure 6). Therefore, active cooling is later installed in the building by installing six air-conditioning units on the roof of each building. The building is heated through city-heating pipes that go through the building in combination with a radiator in each room. The rooms are ventilated by using window grilles for air inflow that is mechanically sucked out of the room.

For more information about this building see table 5.

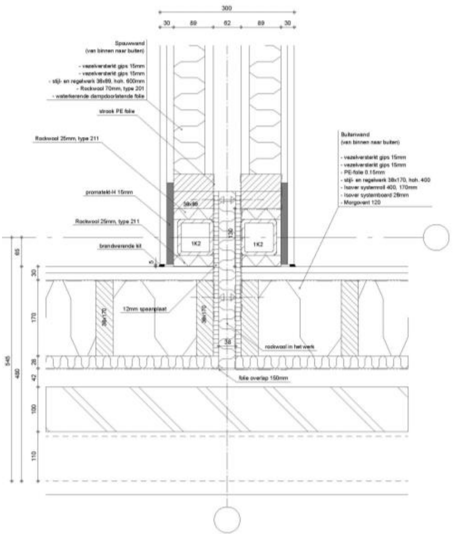
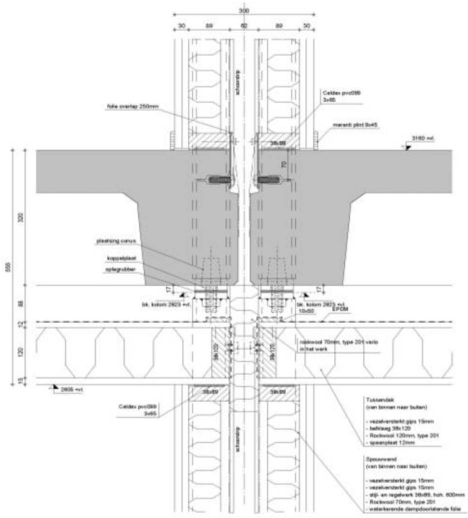
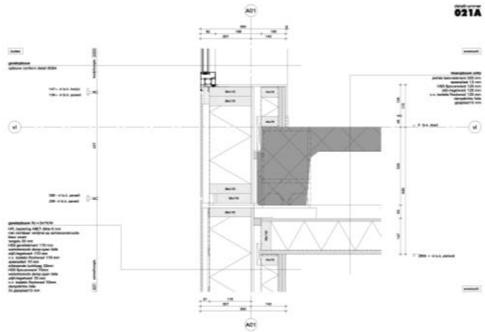
Horizontal detail of the connection of two modules	**Vertical detail of the connection of two modules**	**Vertical detail of the façade and the floor of one module and the ceiling of another module**
		

figure 8: Details Hildebrandpad

5.6.2 UILENSTEDE A+B (AMSTERDAM)

figure 9: Uilenstede A+B retrieved from DUWO

The construction of this modular building started at the end of 2013 and was finished in August 2014.This building consists out of a lower building part that has five storeys and a higher part that has eleven storeys (figure 9). The two building parts together are good for 224 single room student apartments that all have their own bathroom and kitchen (figure 10). The rooms have a total room surface of 28.5m^2 including bathroom and technical space. This building was designed by Studioninedots and realised by modular manufacturer Ursem. The building uses a modular building system that uses a concrete floor with a steel frame and a wooden infill for the walls. The modules that are used are 3D room sized modules, which have been produced in a factory and come completely finished with interior finishes. There is however a difference between the lower part of the building and the higher part, because the modules that are used are only self-supporting until a maximum of eight floors. The taller part of the building is eleven storeys tall, which makes that a steel substructure was needed to be able to build this high (see figure 11). For the lower part of the buildings the modules can be directly stacked onto each other, which is a lot easier, and no usable space is lost due to the steel substructure (see Figure 12). The façade of this building was however still built traditionally, meaning that it was build on-site with a scaffolding. This was because of the difficult masonry work that was needed here because the building appearance had to align with the other buildings at Uilenstede.

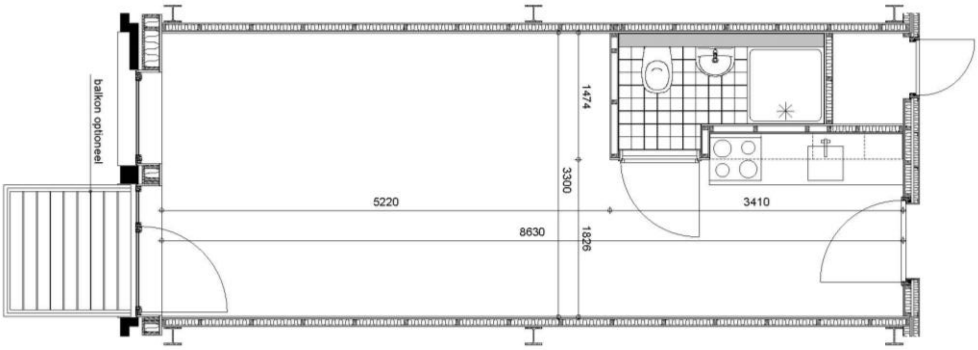


figure 10: student room floor plan Uilenstede A+B

For this building the heating is arranged with city heating in combination with a radiator in the room. The ventilation principle is the same as for Hildebrandpad, meaning that the rooms are ventilated by using window grilles for air inflow that is mechanically sucked out of the room. In this building no active cooling system is used.

For more information about this building see table 5 below.

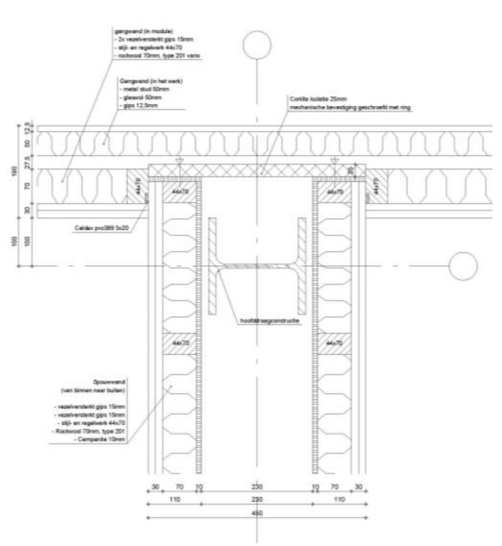
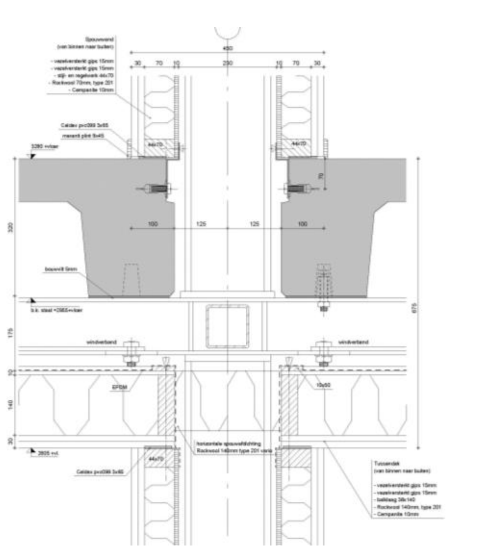
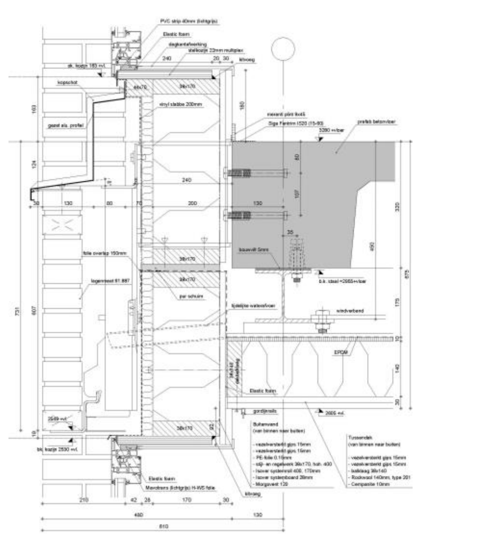
Horizontal detail of the steel substructure in the middle of two modular rooms	Vertical detail of the steel substructure in the middle of two modular rooms	Vertical detail of the façade and the floor of one module and the ceiling of another module
		

figure 11: Details Uilenstede 500-502 building A (11 storeys)

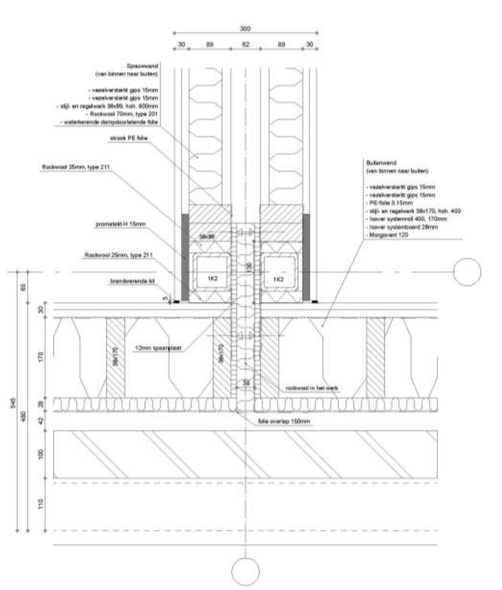
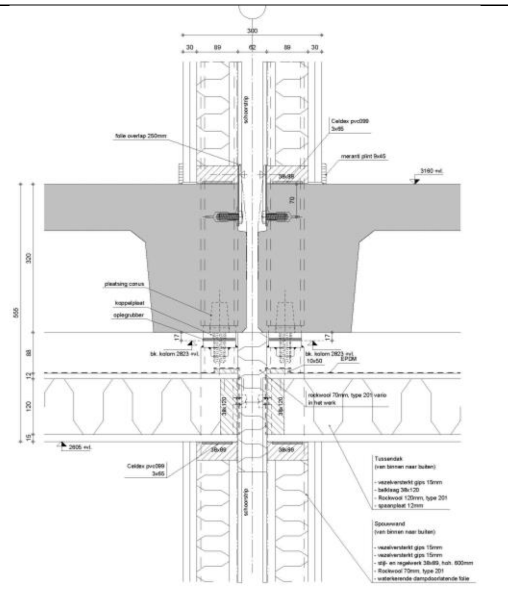
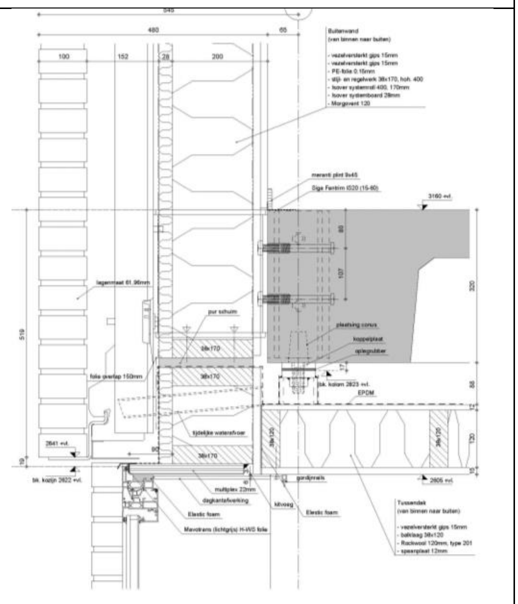
Horizontal detail of the connection of two modules	Vertical detail of the connection of two modules	Vertical detail of the façade and the floor of one module and the ceiling of another module
		

Figure 12: Details Uilenstede 500-502 building B (5 storeys)

5.6.3 LAAN VAN SPARTAAN (AMSTERDAM)

This building is the tallest modular building that has been made in the Netherlands (figure 13). It has three different parts that have different heights. The lowest part has six storeys, the middle part has nine storeys, and the highest part is sixteen storeys tall. In September 2016 the construction of this building started and fourteen months later in October 2017 the building was delivered. The building houses 358 single room student apartments that all have their own bathroom and kitchen (figure 14). This building was designed by Studioninedots and realised by modular manufacturer Ursem.

figure 13: Laan van Spartaan retrieved from DUWO

Because this building is so tall, a different modular building system was used than for the previous two buildings. The modules for this building use a concrete floor with concrete columns with a wooden infill. The modules are attached to each other by pouring concrete into holes in the columns (see figure 15). This means that the modules are very well attached to each other, but there is no possibility of disassembly. Just like the previous buildings the modules that are used are 3D room sized modules, which have been produced in a factory and come completely finished with interior finishes. For the most part the façade was already attached in the factory, so that no scaffolding was needed to construct this building.

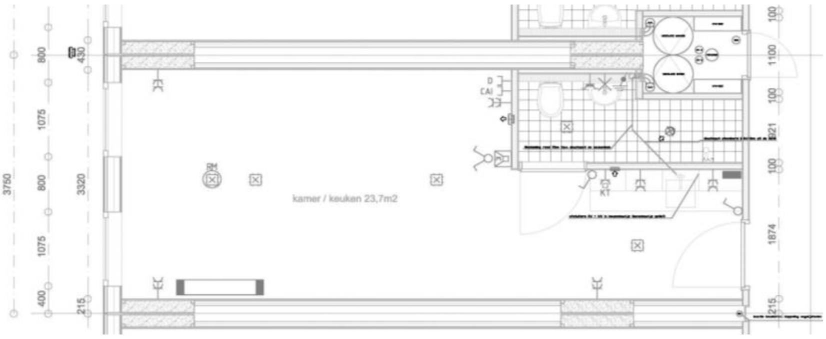


figure 14: student room floor plan Laan van Spartaan

For more information about this building see table 5 below.

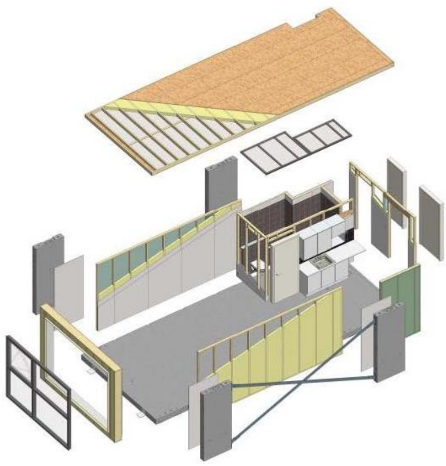
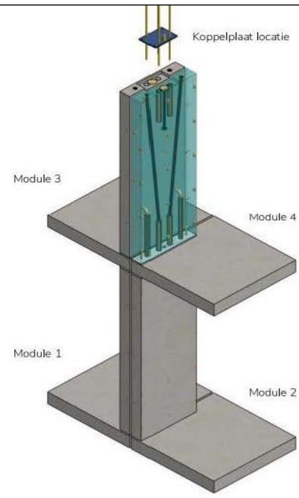
Horizontal detail of the connection of two modules	Exploded view of the module	Vertical connection of the modules
		

figure 15: Technical building information Laan van Spartaan

5.6.4 UILENSTEDE G+F (AMSTERDAM)

figure 16: Uilenstede 510 retrieved from

This building is very similar to Uilenstede A+B, because that building is basically a modular copy of this traditional building (figure 16). Therefore, this building has been chosen as reference to hold against the results of the analysis of the modular buildings. The tallest part of this traditional building has thirteen storeys, and the lower part has six storeys. This means that this building is a bit taller than the modular version. In this building there are 257 single room student apartments of which most have a surface of 30.2m^2, but there are also rooms that have a surface between 45 and 53m^2. All these rooms have their own bathroom and kitchen and there are no common spaces inside of the building (figure 17). This building was designed by Studioninedots and realised by the contractor Van Wijnen.

This building has been made with traditional concrete tunnelling system. This means that all parts of the building are constructed sequentially on-site. What is noticeable is that for the modular building two different modular systems were needed due to the height of the tall building part, but with this traditional version the same wall thickness can be used for the entire building (see figure 18).

For this building the heating is arranged with city heating in combination with a radiator in the room. The ventilation principle is the same as for Hildebrandpad, meaning that the rooms are ventilated by using window grilles for air inflow that is mechanically sucked out of the room. In this building no active cooling system is used.

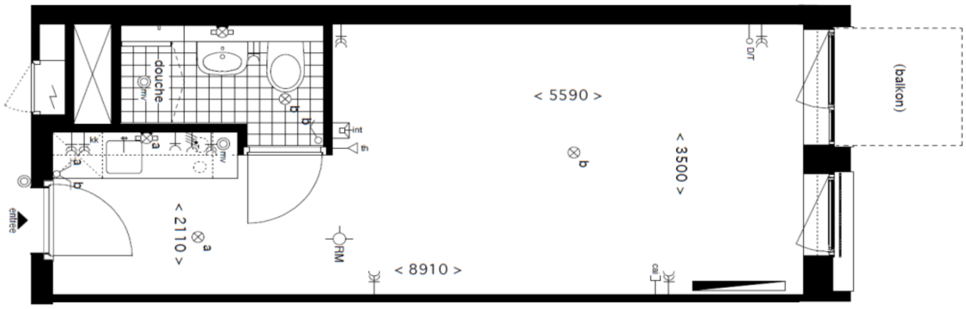


figure 17: student room floor plan Uilenstede G+F

For more information about this building see table 5 below.

Horizontal detail of the concrete separation wall between two rooms	Vertical detail of the wooden separation wall between two rooms	Vertical detail of the façade and the floor that separates two rooms

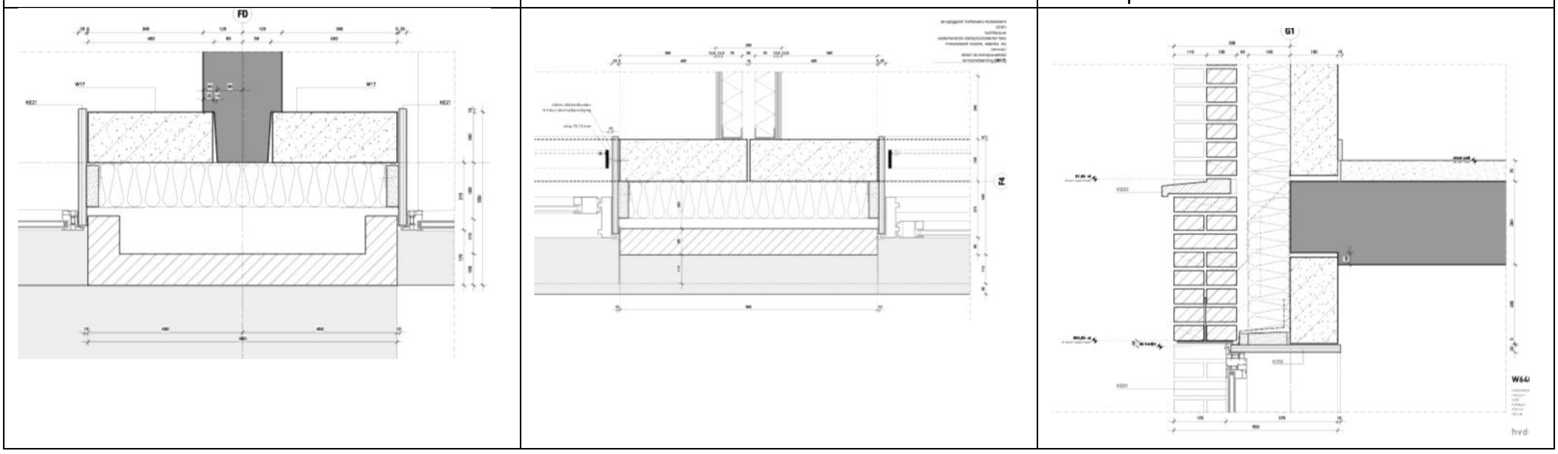


figure 18: Details Uilenstede 510-512

5.6.5 COMPARISON

In this chapter information about the four analysed buildings is presented in two tables. The first table is table 5 in which general technical information can be found about the four analysed buildings. This information gives some background information into the characteristics of the modular buildings and about the traditional building, which can be used as a reference for the modular buildings. In table 6 information can be found about the four buildings related to the different KPI's that were defined in chapter 5.5. This table will be used to check the performance of the modular buildings in the next chapters. All information in the tables was acquired through DUWO.

table 5: Technical building information comparison table

	Modular buildings			**Traditional building**
	Hildebrandpad	**Uilenstede A+B**	**Laan van Spartaan**	**Uilenstede G+F**
Architect	Claus & Kaan	Studioninedots	Studioninedots	Studioninedots
Contractor	Trebbe/Ursem	Heddes/Ursem	Heddes/Ursem	Van Wijnen
Installer	Schouten techniek	Schouten techniek	Schouten techniek	Bogro
Start exploitation year	2011	2014	2018	2013
Storeys	7	A: 11 B: 5	16	G:13 F: 6
Lettable rooms	504	233	358	257
Gross floor area	24.480m²	11.040m²	18.000m²	14.600m²
Usable floor area	15.776m²	7.115m²	11.600m²	9.400m²
Grid spacing	3600mm	A: 3750mm B: 3600mm	3750mm	G: 7500mm F: 7500mm
Level height	3125mm	A: 3280mm B: 3160mm	3000mm	2960mm
Total room surface	28.5 m²	28.5 m²	28.5 m²	30.2 m² or 51,3m²
Bathroom surface	2.6m²	2.4 m²	3.2 m²	2.2 m²
Entrance width	2200mm	1800mm	1870mm	1800mm
Interior width	3320mm	3320mm	3320mm	3500mm
Interior length	8600mm	8600mm	8570mm	8000mm
Separation wall thickness	300mm	A: 110-230-110 = 450mm B: 120-60-120 = 300mm	430mm	G: 250mm F: 250mm
Floor thickness	520mm	A: 180+175+325= 675mm B:225+320=555mm	390mm	280+70 = 350mm
Façade material	Wooden sheets	Masonry	Ceramic sheets	Masonry
Window material	Aluminium	Aluminium	Aluminium	Aluminium
Construction materials	Steel columns in walls that support the weight of stacked units	A: Steel frame + concrete core that houses modules B: Steel columns in units that support the weight of stacked units	Concrete columns in walls that support the weight of stacked units	Concrete walls, floors (concrete tunnelling) + concrete core
Stability	Self-stable units	A: Concrete core B: Self-stable units	Concrete core	G: Concrete core + walls F: Concrete walls
Heating system	City heating	City heating	City heating	City heating
Room heating	Radiator and zigzag from the radiator return in the bathroom floor	Radiator and zigzag from the radiator return in the bathroom floor	Radiator and zigzag from the radiator return in the bathroom floor	Radiator and zigzag from the radiator return in the bathroom floor
Cooling system	Mechanical cooling	None	None	None
PV panels	None	None	48	None

Not for all buildings it was possible to get the information for every KPI, and therefore for some KPI's a hyphen is put in place. This was because the building Laan van Spartaan is contracted using a turnkey contract. This turnkey contract also included maintenance and operation and therefore another company is responsible for the maintenance and operation of the building. This made that it was not possible to get all information about this building. Instead of the missing actual information, the performance requirements from the program of requirements could have been filled in, but this does not contribute to this research, as the actual performance of the buildings is measured and not the theoretical performance.

table 6: Building comparison table using KPI's, which is based on information from DUWO

			Modular buildings			**Traditional**
KPI	***Unit***	***Goal***	***Hildebrandpad***	***Uilenstede A+B***	***Laan Spartaan***	***Uilenstede G+F***
Financial health						
Building speed	months	As fast as possible	14	8.5	13	13
Building speed per day	m^2/day	As fast as possible	58	43	46	37
Total construction cost	€	As low as possible	€28.800.000	€15.800.000	€17.200.000	€19.000.000
Construction cost per lettable unit	€/unit	As low as possible	€57.000	€69.000	€49.000	€74.000
Construction cost per square meter	€/m^2	None	€1176	€1430	€955	€1300
Periodic maintenance cost	€/unit	€501	€140	€94	-	€196
Not periodic maintenance cost	€/unit	€207	€143	€205	-	€340
Sustainability						
Insulation value floor – wall - roof	m^2K/W	3,7 – 4,7 – 6,3	3,0 – 3,0 – 3,0	4,0 – 3,5 – 5,0	3,5 – 4,5 – 6,0	4,0 – 3,5 – 5,0
Heating and cooling energy use	kWh/m^2	<65	99	86	-	76
Electricity use	kWh/unit	None	862	486	-	495
Heat energy use	Gj/unit	None	8,84	8,85	-	8,30
Renewable energy share	%	>40	0	0	-	0
Building lifetime	years	>50	50	50	50	50
Possibility of reuse	Low/Medium/ High	High	Medium	Medium	Low	Low
Affordability						
Service cost	€/m^2/month	None	61	54	-	53
Rent price	€/rentable unit	>=80% Age -23: €442,46 <=20% Age +23: €633,25	100% = <=442,46	96% = <=442,46 4% = <=633,25	94% = <=442,46 6% = <=633,25	86% = <=442,46 14% = <=633,25
Student satisfaction						
Thermal comfort winter	Low/Medium/ High	High	High	High	-	High
Thermal comfort summer	Low/Medium/ High	High	High	Low	-	Low
Acoustic comfort	Low/Medium/ High	High	-	Medium	-	High
Ease of maintenance	Low/Medium/ High	High	-	Medium	-	Medium
Room size	M^2	>=18m^2	28.5 m^2	28.5 m^2	28.5 m^2	30.2 m^2
Student wellbeing						
Size of common rooms	M^2	0.5m^2 per room, min 50m^2	0	0	0	0
Fire safety	Low/Medium/ High	High	Medium	Medium	-	Medium

5.7 ANALYSIS + PERFORMANCE

In this paragraph the performance of current modular buildings will be measured to know what should be improved. To do this, first table 6 that can be seen in the previous paragraph will be analysed per KPI. These results can be compared against the goals that were determined in chapter 5.5, to check to what extent the current buildings adhere to these goals. Based on this comparison can be determined what needs to be done to improve the performance of modular construction for student accommodations. This performance increase of modular construction is important, because it will give construction companies a better incentive to choose modular construction, thus realizing the advantages that modular construction can offer.

5.7.1 FINANCIAL HEALTH

To check the objective of financial health of DUWO, building speed, construction cost and maintenance cost have been considered. The values for the building speed and building cost have been based on a document called a "dechargebesluit" in which the rentability of the building is discussed, including a small introduction about the building and the building speed. For the maintenance the values have been based on the "jaarrekening" in which maintenance is incorporated.

Building speed

As can be seen in table 6 the building speed of the modular buildings is a lot faster than the traditional building. There is however some difference in the building speed between the three modular buildings. What can be seen is that Uilenstede A+B is built slightly slower than Laan van Spartaan and quite a bit slower than Hildebrandpad if you look at the constructed square meters per day. The reason for this relatively slow construction time of Uilenstede A+B is because the façade was constructed in a traditional way. According to interviewee S2, the reason for this was that the façade appearance needed to fit with the rest of the buildings on the campus and therefore the masonry that had been used for the other buildings needed to be used for this building as well. Normally modular manufacturers can already install a masonry façade in the factory, but this façade was very difficult because it had four different depth levels, which made that traditional construction of the façade was more feasible (interviewee S2). Laan van Spartaan was also not very fast, which also partly has to do with the façade. With this façade ceramic sheets have been used, which were partly applied in the factory, but the seams needed to be closed on the construction site. No scaffolding was needed, but it still takes some extra time to finish the façade. Furthermore, this building is a lot taller, which makes that a different modular technique was used where they used concrete to connect the modules. This process also takes a bit more time than just stacking the modules as was possible with Hildebrandpad. With Hildebrandpad, the complete façade was already attached to the units, which made that the construction went very fast.

There is no real definable goal to which the building speed can be compared and therefore the goal is to build the building as fast as possible. There is a difference in building speeds between the three modular buildings, which means that some building aspects cause that construction goes faster or slower. The main causes are the façade choice and the choice of modular system. When designing a modular building the façade should be carefully considered, because according to interview S2, the façade is the most work intensive element of the building. Because not for all modular buildings the facades were included in the factory, there is still some room for improvement in building speed. Therefore, the performance of modular construction for building speed has been set to medium.

Construction cost

When looking at the construction cost per m^2 gross floor area in table 6 you can see that there is quite a big difference between the four buildings. The land price has not been included in the construction cost and therefore this cannot be the reason for the price differences. It cannot be concluded that modular construction

is always cheaper than traditional construction based on these results. The traditional building is relative to the gross floor area even cheaper to construct than the modular building Uilenstede A+B. The main reason for this is that the façade which counts for about 24% of the total construction cost (see figure 20) is constructed using traditional masonry. The other two modular buildings are however a lot cheaper than the traditional building. For Hildebrandpad this is mainly due to the cheap wooden façade that has already been applied to the module in the factory. Furthermore, this building only has seven storeys and the buildings on Uilenstede have up to 13 storeys. This height difference also makes a difference in the construction price as for the modular building on Uilenstede it was necessary to use a steel substructure, which also drove up the construction price. The reason that the building Laan van Spartaan is quite a bit cheaper than all other buildings, while being the tallest of them all (16 storeys) is mainly because a new modular technique was used, and the façade was for the most part installed in the factory. This new modular technique uses concrete columns instead of steel columns, which makes that no steel substructure is needed anymore when building higher than eight floors. The disadvantage however is that the total cost of ownership will very likely be higher because these modules cannot be reused anymore, because concrete is used to connect the modules.
It is difficult to define a goal for the construction cost because these are calculated per building using a rentability calculation over a period of 50 years. This rentability calculation is dependent on many factors and therefore it is not possible to set a value as a goal. The goal however should be that the construction costs should be as low as possible, while considering the total cost of ownership (TCO). Currently not all modular buildings performed so well on the construction cost aspect, because the modular building on Uilenstede was even more expensive than the traditional building. Therefore, the performance of building cost has been set to medium.

Maintenance cost
The maintenance cost is divided in periodic (PO) and non-periodic maintenance (NPO). Periodic means preventive maintenance that keeps the building up to date, safe and reduces the non-periodic maintenance. According to (DUWO account manager, personal communication, 08-04-2022) this periodic maintenance is important, because it saves DUWO money in the long run, because periodic maintenance is cheaper than non-periodic maintenance. Non-periodic maintenance is not planned and therefore it is most of the time last minute for which service companies will charge extra. The data in table 6 about maintenance is gotten from the financial statements of DUWO from the years 2015 until 2021. 2015 was chosen as a begin date, because the data before 2015 was not accessible. If all data from the beginning of the building was considered the average values could possibly have been lower, because at the beginning of the building there is less maintenance required. This can be seen in figure 19, which shows that the PO and the NPO go up over time for the analysed buildings. The biggest contributor to the periodic maintenance are the building installations, which contribute for about 55% to the total maintenance cost of the three buildings based on the maintenance analysis. Of these installations the elevators contribute for 50%, because they require regular repairs and certificates. What can be seen in the table is that there is a difference between the periodic maintenance cost per unit. Both modular buildings have a lower periodic maintenance cost than the traditional building. The high maintenance costs of the traditional building are mainly because of fire safety measures and research to fire safety. There have been multiple fires in this building and therefore research and changes to the building were needed. Even though the modular building Hildebrandpad has the lowest maintenance cost per unit, the highest costs (60% of the periodic maintenance) to installations were made. This is because this building had a lot of problems with overheating and many different solutions have been tested on the building.

The non-periodic maintenance (NPO) of the traditional building is a lot higher than that of the modular buildings. Together with the maintenance supervisor of Amsterdam I tried to find an explanation for this and therefore the maintenance orders of the two buildings were compared with each other. What could be seen was that the traditional building had double the number of workorders than the modular building on Uilenstede. The main categories that caused for this high number of workorders in the traditional building were electrical installations, heating problems and leaking taps. It was however very hard to identify what exactly caused the high non-periodic maintenance cost as the costs were not coupled to the workorders. An explanation for the lower maintenance cost of the modular building could be that the maintenance of the modular building is easier because pipes and other installations are more easily accessible (DUWO maintenance supervisor, personal communication, 13-04-2022). This is because with modular construction no concrete is used and therefore the installations can more easily be changed or repaired. This idea came from the fact that the traditional building has had quite some problems with leaking heating pipes, which had to be replaced. These pipes were embedded in the concrete and therefore it was very difficult to replace them, and thus cost a lot of money. To exactly know what causes the high non-periodic maintenance cost of the traditional building more thorough research has to be done by comparing all maintenance data of the buildings including the maintenance cost per order.

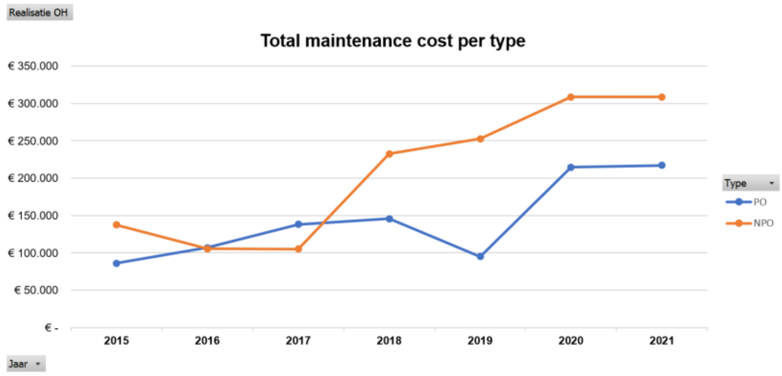


figure 19: Total maintenance cost per type for all 3 analysed buildings combined

As can be seen in table 6 all buildings perform a lot better than the goal for periodic and non-periodic maintenance. This is because this maintenance data only includes seven years, which are part of the first eleven to eight years of the buildings. This means that big installations have not been replaced yet and that these values are missing in the data. If this cost could have been considered values for periodic maintenance would have been a lot higher. Therefore, the maintenance costs go up once the building gets older, which means that if this upwards trend continues the actual non-periodic maintenance cost will be higher than the goal in a few years. Because the non-periodic maintenance cost of the buildings is just below the goal and the expectations are that the average maintenance cost will rise, the performance of the non-periodic maintenance cost is set to medium performance. The traditional building however performs very poorly compared to the maintenance goal and therefore, the modular buildings perform a lot better than this particular traditional building. However, to be able to say that modular construction performs a lot better than traditional construction, a bigger sample of traditional buildings will be needed.

5.7.2 SUSTAINABILITY

The sustainability of the four buildings is determined based on energy use, renewable energy share, building lifetime and the possibility of reuse. In table 6 can be seen that all four buildings are compared against a certain goal. This goal is however hard to define for the buildings, because the sustainability goal of today is a lot different from when the buildings were constructed. The goal that has been filled in is based on the current objectives of the built environment and DUWO, and can in this case serve as an indicator of how much the requirements have gone up and what should be different based on the current objectives.

Insulation value

As can be seen in the table, the buildings that were constructed during the same time period have about the same insulation values. Only the building Laan van Spartaan was build more recently and therefore had to

comply with stricter rules from the bouwbesluit, which shows in higher insulation values. There is no difference between the insulation values used for modular construction and for the traditional building.
It cannot be concluded that the modular buildings perform bad because their insulation is worse than the current goal. This is not fair, because the sustainability awareness and requirements from the government were a lot less when the buildings were built.

Energy use
The energy use of the building is generally quite similar for all three of the four buildings for which it was possible to get this data. The only difference is that Hildebrandpad uses more electricity than the other buildings. This is because in this building mechanical cooling has been installed to prevent the buildings from overheating. This causes for quite a big increase in the energy use in kWh/m^2 of the lettable student rooms. The used energy is for all buildings non-renewable energy because no energy is made in the buildings through for example PV-panels. The energy performance has a lot to do with the insulation value of the buildings and therefore the performance cannot be determined.

Building lifetime
For all buildings theoretical building lifetime has been set to 50 years by DUWO when making financial calculations. DUWO uses these 50 years even though DUWO does nearly never demolish a building (DUWO financial advisor, personal communication, 04-04-2022). According to the financial director of DUWO (interview B9) this 50 years is used, because due to stricter rules generally building materials become better, but also more expensive. When the building is 50 years old, the building needs a thorough renovation which will cost about the same as the original building costs were at the time of construction with less building requirements. Therefore, DUWO uses this 50-year building lifetime for their buildings in which the initial investment should be earned back. The building lifetime could however be set to a longer period than 50 years if more renovation cycles would be incorporated in the maintenance plan. This will make sure that the manufacturer and maintenance team will better adjust the building to function longer than 50 years. Furthermore, this will cause that a more accurate calculation can be made instead of estimating that the renovation will cost the same as the initial building cost. This will provide DUWO with more certainty about the money that needs to be spend, meaning that not too much money is calculated in, which could have been used for constructing other buildings. Therefore, the current buildings perform insufficient on the building lifetime.

Possibility of reuse
Even though DUWO doesn't aim to build for disassembly, most modular buildings can be disassembled if needed on the module level. In the buildings that have been analysed, only Hildebrandpad and Uilenstede A+B can be disassembled. This is because for the lower part of the building (until 8 storeys) the modules were directly stacked onto each other and for the taller part the modules are placed inside a steel substructure. This steel structure is connected using bolts and therefore can theoretically be disassembled if needed. The modular building Laan van Spartaan cannot be disassembled on the module level because concrete is used to connect the modules. Concrete has been used, because of the building height and therefore the modules need to be connected to each other really well. When looking at the possibility of reuse of the module itself not that much can easily be reused. This is because quite some wet processes are used such as welding, tiling, and stucco. This makes that not many materials can be reused on the component or material level.
With rising material prices, material shortages and the environment in mind, the goal of reusability has been set to high. This means that the entire building can be disassembled on module level, but also on the material and component level. Currently no building achieves this goal and therefore the analysed modular buildings perform medium on the possibility of reuse.

5.7.3 AFFORDABILITY

Because DUWO is a social housing association, affordability is a very important objective for DUWO. Affordability of the room is determined based on two important factors, which are the rent price and the service costs. DUWO focuses however more on the rent price, but service cost can also contribute quite a bit to the total rent price as can be seen in table 5.

Service cost

The service cost that students need to pay consists out of cleaning the general rooms, energy and water consumption and if the student wants, they can also pay for internet and a TV connection. In this comparison, only the cost for cleaning, energy and water was considered. What can be seen is that the service cost for the traditional building and the modular building on Uilenstede is about the same. Hildebrandpad however costs a little bit more due to the mechanical cooling system that uses quite a bit of electricity to cool the building. This electricity cost is paid by the resident and therefore the service costs are a bit higher.
There is no definable goal that has been set for the height of the service cost. This is mainly, because it is very hard to know what the service costs will be when designing a building. The service costs are closely related to the energy use of the building, which again is dependent on the insulation value and to what extent passive design has been considered. Therefore, it can be said that these buildings underperform when it comes to service cost, because currently there are much higher standards for energy efficiency.

Rent price

As discussed in chapter 5.4 DUWO has the goal that at least 80% of all rooms that they own are under the "kwaliteitskortingsgrens" and that the rest of the rooms are under the "eerste aftoppingsgrens". For a standard studio with no extra features the rent price is at the "kwaliteitskortingsgrens". Most buildings however have some difficult corners or places where it is more efficient to make the rooms a little bit bigger to maximize the use of space. For these rooms DUWO asks more than the "kwaliteitskortingsgrens". In table 5 this can clearly be seen in the fact that all buildings except for Hildebrandpad have a specific percentage of rooms that are more expensive. Hildebrandpad does not have any rooms that are rented out for more than the "kwaliteitskortingsgrens", because the building only uses a rectangular shape which is ideal for standard DUWO rooms and modular construction. For the traditional building the rooms were not always made more expensive out of necessity, but also some rooms were made double the width on purpose. This was done in the traditional building because the concrete tunnelling that has been used to construct the building is as wide as two rooms. Therefore, it is quite easy to make a double room instead of a single room. With modular construction this cannot be done that easy, because not all modules are flexible, meaning that it is not easy to remove walls in between modules.
DUWO has defined a rent price goal to make the rooms affordable for students. The analysed buildings all go beyond this goal and therefore perform well based on the rent price. That all these buildings perform better than the goal Is because DUWO wants to achieve this goal over their entire portfolio, and they have other living concepts that are bigger than the standard single module sized room. Modular construction is ideal for realising smaller single rooms and therefore these modular buildings are very suitable for the construction of rooms that are at the lowest price bracket.

5.7.4 STUDENT SATISFACTION

To determine the satisfaction of students a survey was made in which questions were asked about how the student experiences the room and how satisfied the student is with the room. This survey was sent to residents of the analysed buildings Uilenstede G+F and Uilenstede A+B. These two buildings were selected, because these buildings are very similar in appearance and form, but one building is constructed using modular construction and the other one is constructed using traditional construction. That the buildings are so similar in form provides a good comparison case to analyse how modular construction performs against traditional construction. This survey included questions about thermal comfort, ease of maintenance, acoustic comfort and satisfaction with kitchen and bathroom. The survey was sent to a total of 418 students divided over the two buildings, which resulted in an almost equal division of 42 responses over the two buildings. To start the survey, the question was asked how satisfied the students were with their room in general. The result was that the modular building was graded with a 4,1 out of 5 and the traditional building with a 4,0 out of 5, which means that the students are quite satisfied with their building. Below the student answers to the questions in the survey will be analysed.

Acoustic comfort

The survey asked how the user experienced the acoustic comfort of the building. This question was for both modular and traditional building graded with a 3,5 out of 5. In the explanation paragraph not many students included a reason for this relatively low number. The building is located quite close to the airport and some students explain that they experience some noise disturbance from these planes, which makes that they cannot open the window. Furthermore, some students that live on the top-floor of the modular building experience noise disturbance from the planes even when they have closed the windows. This is most likely, because the roof of the modular building is made from wood, which does not reduce direct sounds as much as concrete, which is used for the roof of the traditional building.

The goal is that students experience minimal noise disturbance when they live in a DUWO building. The modular building performs medium on the field of acoustic comfort, mainly because residents on the top floor experience noise disturbance from the planes, because the building structure of the roof doesn't reduce the sound enough. That this building performs medium is however only because the building is situated close to the airport. Therefore, can be said that overall, the analysed buildings perform good if the building was not situated close to the airport.

Thermal comfort

The questions in the survey about thermal comfort were divided in summer and winter. The results between summer and winter were very different. In winter the students rated the thermal comfort of the modular building with a 3,9 and of the traditional building with a 4,1. Some students indicate that they experience a difference in temperature in the room in the winter, with the side of the window being quite cold. The main issue about which most students complain is the temperature in summer. Students rate the thermal comfort in summer with a 1,8 for the modular building and with a 2,4 for the traditional building. Both buildings become way too hot in summer, and students indicate this is because there is no sunshade, there are big windows and because it is not possible to ventilate the room or hallway. The different scores between the modular and traditional building are most likely caused by the wooden roof of the modular building. This wooden roof is covered with black roofing material which becomes extra hot in summer and the heat can quite easily transfer through the wooden structure. This resulted from the student survey, because students that lived in the top of the modular building rated the thermal comfort in summer with a 1. Hildebrandpad scored very good on thermal comfort in summer, but this is because mechanical cooling was installed after many overheating complaints of students. Because of these complaints a professional analysis was done to see where this overheating came from. The building has a black façade, which many people held accountable for the overheating. Based on calculations the extra heat that is generated due to the black colour is 55% (3,06W/m^2) more than with a white façade, which results in a temperature increase of 28%. This black façade however covers only 20% of the façade, which means that 80% consists out of solar control glass. The direct heating from the sun inside the room is a lot bigger (328W/m^2) and therefore can be concluded that the black façade is not the main cause of the heat problem. What was also considered is the extra heat due to ventilation air that came into the room via the

window. This ventilation air is warmed due to the black façade and therefore is a bit warmer than normal. This contributes to 373W extra heat, which is not much according to the report. The conclusion is that the black façade contributes to some heat increase inside the building, but that the main cause is the direct sunlight inside of the room. What also contributes a bit to the overheating is that the building uses city heating, which means that there is always warm water flowing through the building even if the user has their radiator turned off. Furthermore, there is very little possibility of ventilation in the room because only one window in the room can be opened and no ventilation can come from the corridor.
The thermal performance goal is set to high in both summer and winter. In winter the buildings perform well, because in winter the students rate the thermal comfort very high. In summer however the building performs very poor, because many students complain about overheating and therefore, they also rate the thermal comfort in summer very low.

Ease of maintenance
Students rated the ease of maintenance of the room with a 4,2 for the modular building and with a 3,9 for the traditional building. This shows that students are quite satisfied with how easy the room can be cleaned and maintained. Some comments however were that the bathroom cannot be cleaned that easily due to the small tiles that are used on the walls and floors. These small tiles have many grouts, which require regular intense cleaning for them to stay clean. Furthermore, for the modular building shower trays have been used instead of a tiled floor with a drain. There is no curtain or door that prevents the water from spilling next to the shower tray, so some students experience that it is hard to remove this water. These analysed buildings are quite new (10-12 years) and therefore the students did not experience aspects of the building that are not easy to maintain anymore due to a lack of maintenance. DUWO has done a survey in which they targeted students of an older building that was constructed in 1970 and renovated in 1991. In this survey they asked the students to evaluate their bathroom. This building has similar looking rooms and bathrooms and therefore can be used to check how the bathrooms perform in the long run. In this survey Students complain about stains and dirty tile grouts that cannot be cleaned anymore. Also, too much calcium has attached to the tiles, which cannot be removed anymore. Students ask for “normal tiles”, because these tiles that are used in this bathroom are white 10x10cm tiles, which are very old and not easy to clean. Furthermore, there is mold on the walls where there are no tiles. Students indicate that this mold is caused because the ventilation of the bathroom is very bad. This is also the case for the newer modular and traditional building because students indicate that the ventilation in the bathroom is very minimal.
The goal for ease of maintenance is set to high, because this is beneficial for DUWO as well as for the student. This is because if a room is easy to maintain the entire room and especially the bathroom will last longer, which saves DUWO money on renovation costs. The performance of ease of maintenance of the modular buildings is set to medium, because of the water spilling and because the grouts become uncleanable after several years.

Room size
Students indicate that they are happy with the size of their room. This is not surprising as the size of the student rooms are quite big, considering that the smallest room that DUWO currently offers (Sting) is only 18m^2 in size and the biggest room (Studio) is currently 26m^2. Based on an interviewee B5 the room size that DUWO realises has been decreasing because of increasing construction prices. DUWO decreases the room size to realise affordable student rooms, which they think is very important. Interviewee B1 said that it is important for DUWO that the student is satisfied and therefore they aim to realise a student room that is as big as possible while keeping the rooms affordable. Therefore, the analysed buildings perform good when it comes to room size. This performance has however decreased lately because small student rooms are being realised.

5.7.5 STUDENT WELLBEING

DUWO does yearly student satisfaction surveys in which they ask students about aspects such as safety, building maintenance, hygiene, and social aspects. Based on these student surveys and the motivations of the students in these surveys it is possible to check the student wellbeing for the buildings Hildebrandpad, Uilenstede A+B and Uilenstede G+F.

Common rooms

For all three buildings students indicate that they would like a common room in the building so that they can socialise with other building residents. Currently there is no place in the building to meet people and all student rooms are individual in the buildings, meaning that students nearly never have contact with other residents. Students indicate that especially during the covid time they missed that the buildings didn't offer a place to meet other people.

DUWO has set the goal that every building should have a common space. Back when these buildings were built this goal was not there and therefore, the buildings don't have a common room, which leads to insufficient performance in relation to common rooms.

Fire safety

All three buildings use basically the same student housing concept and therefore all student rooms and facilities are basically the same. Therefore, students experience the same issues with fire safety in the different buildings. The main concern of the students is that there are no instructions or equipment of what to do when there is a fire in the building. Furthermore, because there is no extractor hood in the kitchen the students remove the batteries of the fire alarm, because the alarm will turn on when cooking.

Every building should be as fire safe as possible to prevent casualties from a fire. Therefore, the goal of fire safety has been set to high. It can be assumed that the buildings follow the rules of the building code about fire safety. Therefore, theoretically the buildings should be fire safe, but still quite a bit of fires have occurred in DUWO buildings recently. In the non-periodic maintenance cost for all analysed buildings, costs for renovations due to fires have been made. Through the survey the students indicated that there was a lack of equipment and instructions, and therefore the performance related to fire safety of the buildings is medium.

5.7.6 CONCLUSION

In the chapters 5.7.1 to 5.7.5 the results from the comparison table in chapter 5.6.5 have been analysed and the performance per KPI was determined. This has been done for every KPI to get an overview of the performance of the analysed buildings. The results from this performance measurement can be used to see which building aspects have to be changed to improve the performance of modular construction for student accommodations. In table 7 a summary can be seen of the performance of the analysed modular buildings. This summary shows that quite some KPI's perform medium to insufficient, but also some KPI's perform good. In chapter 6 per objective recommendations will be given to increase the performance of modular construction for student accommodations.

table 7: performance summary table

Objective	KPI	Performance	Definition of performance
Financial health	Building speed	Medium	The building speed performs better than the traditional building, but for most buildings some façade finish still needed to be done on site, which makes that the building speed can be increased and therefore the performance is set to medium
	Construction cost	Medium	The older buildings perform less, while the new modular building performs good, therefore the performance is set to medium
	Maintenance cost	Medium	The modular buildings perform better than the traditional building and better than the goal. However, the trend is that the maintenance cost will rise over time and therefore the buildings perform medium on the maintenance cost
Sustainability	Insulation value	-	Cannot be said due to changing regulations and standards
	Heating and cooling energy use	-	
	Renewable energy share	-	
	Building lifetime	Insufficient	DUWO uses an exploitation phase of 50 years, which makes no sense for all building parts, which results in insufficient performance
	Possibility of reuse	Medium	Not all buildings can be disassembled and buildings that can be disassembled can only be disassembled on the building sector cell level (see chapter 3.1.1)
Affordability	Service cost	-	Cannot be said due to changing regulations and standards
	Rent price	Good	Is related to the financial health of DUWO, but considering that DUWO achieves their ambitious goal the performance is set to good
Student satisfaction	Thermal comfort	Medium	The buildings perform well in well in winter, but in summer the buildings overheat
	Acoustic comfort	Good	The building performs good, the only complaint is that the building is situated close to the airport and there is some sound disturbance at the top floor
	Ease of maintenance	Medium	Mainly the bathroom is not easy to clean due to small tiles and many grouts
	Room size	Good	The analysed buildings have big rooms that are well above the standard
Student wellbeing	Fire safety	Medium	Building complies with building codes, but students feel not safe
	Size of common rooms	Insufficient	There are no common rooms in the analysed buildings

6 PERFORMANCE IMPROVEMENT

This chapter will explore solutions that can be used to increase the performance new built modular student accommodations by giving recommendations for the social student housing association DUWO. Even though the recommendations are specific for student accommodations and social housing corporations, most of them can also be used for modular construction in general. The performance measurement that was done in the previous chapter is used in this chapter to know which building aspects could still be improved and what is important to improve. The recommendations for performance improvement are based on interviews with professional stakeholders which can be found in chapter 2.2.3.

In the previous chapter, 5 main objectives were determined which are: financial health, sustainability, affordability, student satisfaction and student wellbeing. For every objective, KPI's have been formulated, and the performance of every KPI has been measured for three modular buildings. Some KPI's performed better on average across the three buildings than others and therefore in this chapter not all objectives will be discussed. No recommendations will be given for the objectives affordability and student wellbeing, because no direct performance improvements can be made through modular construction. Below per objective this will shortly be explained in more detail.

Affordability

Affordability was split into two KPI's that determine the affordability of the room for the student. This is rent price and service cost. The performance of rent price was good, because DUWO realises student rooms that are under the "kwaliteitskortingsgrens". Furthermore, the rent price is coupled with the financial health of DUWO and therefore if modular construction would perform better on this objective automatically it will perform better on rent price as well. This is because DUWO is a social student housing association, and they are not allowed to make a profit. This will make sure that if DUWO has to spend less money on constructing and maintaining the buildings this extra money will automatically go to the students. The service costs consist out of cleaning the building, energy cost and other services. Modular construction can only influence the energy cost by requiring less energy for heating and cooling. This will however also already be discussed in chapter 6.2.3.2 about passive design which will reduce the service cost for the student. Because of these reasons the objective affordability will not be directly discussed in detail in this chapter.

Student wellbeing

Student wellbeing was split into the KPI's fire safety and size of common rooms. The measured buildings performed not that good on fire safety in the previous chapter, because there had been quite a few fires and students did not feel safe, because there was no equipment to extinguish fires. Based on personal communication with interviewee B5 the reason that there is no equipment to extinguish fires is that DUWO does not want students to "play firefighter". This would put the student at risk and therefore DUWO has decided to not include fire extinguishing equipment in the building. Furthermore, the building is technically fire safe, because it follows the rules of the building code and the fire department is generally involved in the design. Because of this it is not necessary to further elaborate on fire safety in this chapter. What would however have been interesting to research is the performance of building fire safety in the light of durability of the building structure. Currently it is the aim of the fire department and the building codes to make sure that people can flee safely, and it doesn't matter if the building collapses or needs to be demolished due to damages. This has however a big negative environmental impact if the building burns down and has to be rebuilt. Therefore, when designing buildings, next to the fire safety of people also some attention should be given to the durability of the building, so that the building structure will stay usable in case of a fire. The analysed buildings performed bad on the size of common rooms, because no building has a common room. Recently due to corona it has become a goal of DUWO to include common space in their buildings, because they noticed that students want to meet fellow resident. Therefore, for new buildings DUWO has the rule to include at least 50m^2 of common space in their buildings. Because this is already a rule, and it is possible with modular construction to make a common space it is not necessary to further elaborate on this in this chapter.

6.1 OBSTRUCTIONS

In chapter 4.2 the obstructions for the uptake of modular construction that were found in literature and through interviews have been elaborated upon. The initial thought was that these obstructions could be intertwined with the performance improvements that are proposed in chapter 6. This is however not possible for all obstructions as not all obstructions fall under an objective. Furthermore, this research focuses mainly on increasing the performance of modular student accommodations from the perspective of DUWO, which is a developer, client and investor and therefore this is also the audience of this graduation research. In the chapter about obstructions, for the three groups buyers, suppliers and government, the obstructions have been documented. Because the audience of this research is buyers, which includes developer, investor and client, the barriers for the suppliers and the government will not be discussed here. In the few subchapters that follow, the obstructions for the developer, client and investor will be discussed shortly and possible solutions to overcome these obstructions will be discussed.

6.1.1 DEVELOPER

As discussed in chapter 4.2, a great obstruction for the developer to use 3D modular construction is that 3D modular construction does not always fit the building plot. This is because 3D modular construction is very standardized and therefore it is not efficient to make custom modules that fit the building plot. This would reduce many advantages of modular construction such as the reduced construction cost and the increased building speed and therefore modular construction doesn't become a viable option anymore. If not all buildable area of the building plot is used, modular construction becomes not an option anymore for most developers, because they want to realise as many square meters as possible. If they would realise less usable square meters the price of the building is lower and therefore, they will make less of a profit. For DUWO as an investor, fewer realised square meters means less income from rent over the entire building life, which adds up to a significant loss over time. This is probably the biggest obstruction for the use of modular construction from the perspective of the developer resulted from personal communications with interviewee B1, B2 and B3.
Not only the shape of the building plot influences the suitability of modular construction, but also the building area that is determined in the zoning plan by the municipality can be an obstruction for modular construction. The municipality determines a set building area that is allowed to be built on and it is not allowed to build outside of this building area. Based on interviewee S6 and S7, modular construction often involves a standardised width, which means that buildings can become wider in increments of this set width. Because with modular construction the width can only be expanded in increments of the standard width, often not the entire building area can be used. This is not beneficial for the developer as they want to realise as much building area as possible and therefore the zoning plan can also be an obstruction for modular construction. Furthermore, this same zoning plan often specifies a maximum building height as well. As was also discussed in chapter 4.2 modular construction requires a higher level height to achieve the minimum of 2600mm floor to ceiling space that needs to be realised according to the building codes. This is because 3D modular construction involves a floor and a separate ceiling and with traditional construction the floor and ceiling are the same element. That space is lost can be seen in table 5 which shows that all modular buildings lose between 40mm to 320mm in height compared to traditional construction. This also resulted from interviews with modular manufacturers in which they all indicated to lose some space compared to traditional construction. Based on personal communication with

interviewee B3, this extra building height can be a big obstruction, as for some projects this will mean that one less storey can be realised.
According to personal communication with interviewee B3 it is possible to request a deviation from the zoning plan to change the building area or the building height, but this generally takes a lot of time and therefore this is not often done. To maximize the use of the defined building area, interviewee S7 said that they combine modular construction with traditional construction for the deviating building parts to combat this issue. This will however reduce the construction speed and the cost reduction advantage and therefore the use of traditional construction should be reduced as much as possible. That the suitability of the building plot and the zoning plan can be an issue for modular construction should be realised before the start of a project, so that this issue can be dealt with. According to interviewee S7 this can be done by approaching the modular manufacturer at the very start of the project before a design is made, so that together with the modular manufacturer options can be discussed and possibly a meeting with the municipality can be arranged. All modular manufacturers that were interviewed were asked how they deal with this issue and most of them did not directly answer this question. In this graduation research no solution was found to eliminate this obstruction completely and therefore some more research needs to be done on how to reduce this obstruction even more. As long as this obstruction is still present, according to interviewee B5 it would help if DUWO would make a checklist which can be used to determine if modular construction is suitable for the building plot and what should be considered when using modular construction. I experienced that DUWO employees often don't exactly know if specific buildings can be realised with modular construction and therefore this checklist will help them understand if modular construction can be used and what kind of implications it will have on the project.

6.1.2 INVESTOR

In chapter 4.2 was said that the risk of the modular manufacturer failing to deliver is an obstruction for the use of modular construction from the standpoint of the investor. Also was said that this risk could be reduced if the modular manufacturer could provide a guarantee that they will deliver. In chapter 6.2.1.6 this guarantee will be discussed in more detail and recommendations will be given about how to reduce this risk and this obstruction at the same time.

6.1.3 CLIENT

An obstruction for the client can be that they should know every building detail very early on in the building process. This also includes that the client cannot make late changes to the building design anymore. Even though this was seen as an obstruction for modular construction in literature this was no real obstruction for DUWO. The main reason for this is that DUWO builds very standardised buildings using a standardised program of requirements. This means that DUWO already very early on in the project knows what they want based on experience with previous projects. Therefore, this obstruction is no real obstruction for DUWO and other experienced clients.

6.2 FINANCIAL HEALTH

The financial health is an important objective because this makes sure that DUWO can keep providing student accommodations. Because this is so important, in this chapter, measures to improve the financial health of DUWO will be elaborated upon. This will be done by providing recommendations that can be used to improve the performance of the following three KPI's: construction cost, building speed, and maintenance cost.

6.2.1 CONSTRUCTION COST

The initial construction cost is the first KPI that determines if DUWO can keep constructing buildings, while staying financially heathy. At the time of writing this graduation thesis, the increasing energy price and the war in Ukraine has a big effect on the building material price and therefore the cost of constructing a building is rising. Because of this rising cost, many contractors and developers are struggling to build buildings that are still profitable for them. DUWO is a social housing association for students and their main goal is to make affordable student rooms, but due to the rising building cost it is currently very hard to build affordable buildings. As indicated in chapter 4.1, modular construction can provide a cost reduction compared to traditional construction. There is however a bit of doubt in literature that modular construction really is cheaper than traditional construction. Based on interviews with modular manufacturers, the initial building cost are at least similar to traditional construction, but if enough standardisation is implemented, the cost savings are around 10% compared to traditional construction. This was confirmed by interviewee S4, but they are aiming to achieve cost savings of 15% using automation in their factory. That modular construction can be cheaper than traditional construction also resulted from the analysis of the case study in chapter 5.7.1., but the condition for this cost saving is that the façade should be included in the module. Next to the initial cost savings modular construction can also contribute to a decreased total cost of ownership (TCO), which will be discussed in chapter 6.2.3. In this chapter measures will be discussed that should be used to make modular construction perform better by reducing the initial building cost.

6.2.1.1 STANDARDISATION

In chapter 3.1.2 was indicated that standardisation should be implemented well beyond individual large projects. This way industrialisation is possible, which increases the building speed and reduces the production cost of the modules. Due to the housing shortage, many social housing associations are trying to increase the housing production by building houses that are standardised and can be repeated all over the city (Haagwonen, 2022). These houses are standardised but are not all the exact same due to the use of different materials for the façade. Currently DUWO has a fairly standardised program of requirements for every living concept, but they do not use a standardised building system for all their buildings. Currently this standardized program of requirements does not lead to mass production, because DUWO uses different contractors and modular manufacturers that all bring some of their own preferences into the building. This causes that the buildings are fairly similar, but they are also all a bit different and therefore not standardised. To achieve standardisation and the advantage of building cost reduction with it, DUWO can do two things: 1)they can make a standardised modular design that represents the DUWO standard and that will be used for all suitable DUWO buildings or 2) they can reduce the amount of standardisation in their program of requirements and leave the standardisation to the modular manufacturer by making a performance based program of requirements (see chapter 6.2.1.2).

The first option is possible for DUWO, because they are the biggest student housing association in the Netherlands, which means that they have a relatively high yearly building volume. This is important, because if DUWO would make a specific standard, a modular manufacturer needs to make investments to produce this standard, so it will only be financially feasible if there is a high production volume possible. The higher this volume, the more advantages would be generated from using a DUWO standard and therefore DUWO should also investigate partnering with other student housing associations (see chapter 6.2.1.4). The development of a DUWO standard module will require quite some investment from the modular manufacturer as well as from DUWO. Therefore, it is important that DUWO makes a contract for multiple years with one specific modular manufacturer. The advantage of DUWO making a standard module for the construction of all their buildings is that the modules will not have to be produced just on time, but it would be possible to build a surplus of modules, which reduces the risk of just in time production. Another advantage is that DUWO themselves can keep improving this standard module so that it becomes better over time, and that DUWO can make the module exactly how they want it. Next to the big investment in time and money that DUWO needs to do a disadvantage is that DUWO will need to commit to a contract for multiple years with one modular manufacturer. This involves some risk for DUWO, because it is hard to estimate the demand in a few years.

The other option is to leave the standardisation to the modular manufacturer. To do this, DUWO should make a performance-based program of requirements in which they only describe how a DUWO building should perform (see chapter 6.2.1.2). Based on interviews with multiple modular manufacturers, there is a big difference between modular manufacturers when it comes to standardisation. To achieve the most advantages out of modular construction, the size, quality and detailing of the modules should be standardised. Not all modular manufacturers standardize on all three aspects and most manufacturers only standardize the detailing and quality of their products and let the customer be free in choosing the dimensions of the module. This way the modular manufacturers have a big market reach, because they can basically realize every building, but this way the maximum cost reduction is not achieved. Interviewee S2 called this low amount of standardisation their strength, but also their weakness. Other modular manufacturers such as interviewee S1, S6 and S7 use a much more standardised approach. They standardise on the module level, meaning that the size, quality, and detailing are all standardised, which makes that they can work very efficient. This is so efficient, because they don't have to change moulds for the concrete floor and all parts of the module can be premade to reduce the risk of downtime in the factory. This realises a big advantage in cost reduction, which is especially beneficial for social housing associations like DUWO. This is because the buildings of DUWO often are very similar and not much variation is needed, and an important objective is to realise affordable houses. With this standardized module variation can be achieved through combining multiple modules into a set number of possible floorplans. Furthermore, the façade is not included in their very strict standard, which means that every building can have a different façade. The advantage of choosing already standardised market products is that it will require much less effort and money for DUWO to benefit from standardisation. The disadvantage of using this option is that DUWO will be less in control over how the building will precisely look like and will only be in control of how the building will perform. Furthermore, by using multiple standardised market products DUWO buildings will differ in appearance. This can be seen as a disadvantage by DUWO, because they like to have a DUWO look to the building, but this can be overcome by contracting one or a few modular manufacturers.

6.2.1.2 PERFORMANCE BASED PROGRAM OF REQUIREMENTS

According to Spekkink (2005), "The performance Approach is the practice of thinking and working in terms of ends rather than means". So basically, a performance-based program of requirements describes what a building is required to do and not how it is constructed. The advantage of using a performance-based program of requirements is that the building experts are free to choose how they construct certain building parts and are not restricted by specifications in the program of requirements. This stimulates innovation and therefore building cost can be reduced. Other advantages of a performance-based program of requirements are according to Spekkink (2005):

1. It helps clients, designers, and contractors to gain better knowledge about how a building operates or should operate.
2. It leads to cost effectiveness, better quality and better client and user satisfaction.
3. It prevents designers from tumbling into solutions from the very beginning without proper understanding of the real client and user needs.
4. It offers better conditions for creativity and for generating added value.

The reason why performance-based programs of requirements are not always used is because not all quality aspects can be translated into performance specifications. Furthermore, due to the traditional segregation of the design, engineering and the construction discipline, every party would come up with a different solution because that solution fits best with them. Another reason for not using a performance-based program of requirements (that is specific for big housing associations like DUWO) is that DUWO is also responsible for the maintenance of a big building portfolio. To effectively maintain all these buildings, the interior elements that have to be repaired or replaced regularly should be standardised so that the inventory of spare parts can be as low as possible.

As described in the previous paragraph, DUWO has the option to make a standard module themselves or to use a standard from the market to be as cost efficient as possible. The use of a performance-based program of requirements has the advantage that it enables innovation. This is wat DUWO needs because they need the construction of buildings to become cheaper. Therefore, DUWO needs to make a performance-based program of requirements for both the option to use a market standard, but also for the option to make a DUWO standard themselves. Based on this performance-based program of requirements the modular manufacturer can start producing modules or the modular manufacturer can together with DUWO come up with a DUWO standard. When using a market standard, according to interviewee S6 and S7, a performance-based program of requirements has to be used to effectively implement modular construction. This is because they implemented a standardisation in their modules that goes beyond a single large building (see chapter 3.1.2). Therefore, if DUWO has its own standard specific program of requirements it is not possible for the modular manufacturer to use their standard, which will drive up the cost.

A performance-based program of requirements is very suitable for modular construction, because the obstructions are a lot less than with traditional construction. This is because with modular construction it makes a lot more sense to leave the whole construction process with the modular manufacturer from design to maintenance. This is because every modular manufacturer uses their own technique, and most architects are not up to date with all modular building systems. Therefore, the obstruction of different disciplines with different objectives can be reduced and the modular manufacturer can make an optimal design that fits best with their modular system. Also, many modular manufacturers prefer to include maintenance in their products, because they know best wat needs maintenance in their products and want to do preventive maintenance. If DUWO would make an agreement with modular manufacturers about the maintenance of the building, the modular manufacturer can decide what materials or building technique should be used. When choosing the materials or building technique for the building the modular manufacturer will take the total cost of ownership into account, which they can do a lot better than DUWO, because they have more knowledge about the product. Therefore, a performance-based program of requirement fits well for the use of modular construction.

Currently DUWO specifies in their program of requirements that specifically Mosa Holland 2050 Classic tiles should be used for the tiling of the walls and floors in the bathroom, they specify the type of sink and toilet that should be used, and they specify that heating should be done via a radiator in the room. Furthermore, they state in their program of requirements that they prefer masonry as a façade cladding due to it being maintenance friendly. All these specifications in the program of requirements hinder the use of new innovative materials, which also was the result of interviews with interviewee S2 and S5. They indicated that there is a shortage of people that can perform traditional labour trades such as tiling, stucco or masonry. Because this labour shortage will continue to grow and therefore construction cost will rise, we should stop using these traditional materials that are prescribed by DUWO. Also, DUWO should not specify cooling heating and ventilation systems in their program of requirements, but they should let the modular manufacturer determine which system is best. Interviewee S5 said that they have experience with a specific system and that they are standardising this system. Therefore, this system is well integrated in their modular units and is the most cost efficient. As can be seen in figure 20 the installations contribute to 29% of the total building cost, so standardizing them can make a big impact in the cost.

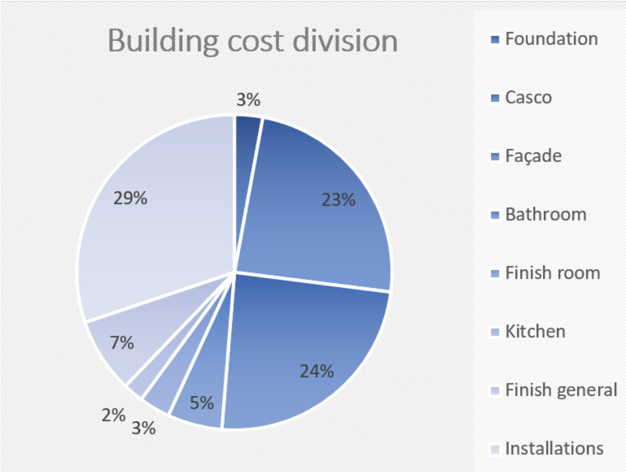


figure 20: Building cost division based on a building invoice of a DUWO building from 2020

6.2.1.3 CONTRACT A MODULAR MANUFACTURER

Based on interviewee S3, who are expecting to finish building a modular factory by the end of April 2022, the continuity of this factory will be crucial for its success. This is so important, because the factory requires a big investment and if the factory would be idle the lost revenue will have to be recovered through price increases. Many stakeholders choose modular construction, because it offers a reduction in construction cost and therefore a price increase would not be beneficial for the use of modular construction. Interviewee S5 said something along these lines as well, and they said that they could even provide a discount if a purchasing agreement could be made. Through this purchasing agreement DUWO would be obliged to take a set number of modules over a specific period, which would give the modular manufacturer more certainty. According to interviewee B10, housing associations already do this a lot with traditional contractors. They make a contract with a contractor that they for example will take 1000 houses from them over a period of three years. By doing this, the contractor can order the materials for these houses in bulk, and therefore the building price can be reduced. Furthermore, it gives them security of work so that they can anticipate on this, which reduces their risk of downtime. Social housing associations such as DUWO are allowed to make a contract with a contractor that they choose, because they are not seen as a government organisation and therefore, they don't have to follow the European rules of public procurement. DUWO however has internal procurement rules to which they have to comply, which serve to give transparency to the choices that DUWO makes when developing a new building. When procuring a new development, the developers can choose out of the following four procurement methods: Multiple private tender, public tender, building team and a TurnKey contract. The most suitable procurement method for contracting a modular manufacturer is the multiple private tender in which a minimum of 3 manufacturers make a bid. According to interviewee A1, this is because this way DUWO could ask multiple modular manufacturers to make a design for a DUWO module combined with a price that is based on the performance-based program of requirements that is discussed in chapter 6.2.1.2. Based on these results DUWO can select the modular manufacturer that scores best in the tender and grant that manufacturer a contract for a set number of modules over a period of time. This is possible, because DUWO currently uses a very standardized program of requirements with seven different living concepts of which the three concepts that are used most (studio, studette and sting) are very similar and only differentiate in size. Therefore, they can make this contract with the modular manufacturer, because DUWO can already estimate how many similar modules they will need in the coming few years.

6.2.1.4 WORK TOGETHER

Many social housing corporations currently work together to build faster, smarter, and cheaper in the program called "de bouwstroom" (Aedes, n.d.). This program is developed by the overarching social housing corporation Aedes to combat the housing crisis by increasing the building speed. In this program social housing associations work together and make the shift from traditional construction to modular construction. By working together, the housing associations can together buy modular houses in big numbers and make contracts with modular manufacturers as discussed in subchapter 6.2.1.3. DUWO should also try to work together with other student housing associations to share knowledge and together make a contract with modular manufacturers. There are a lot less student housing associations than there are normal social housing associations, but there are still thirteen social student housing associations that are part of the overarching student housing association Kences. All these thirteen student housing associations are good for a total of 88.000 student rooms, of which DUWO provides 33.000 and is therefore the biggest student housing association in the Netherlands. DUWO has the goal to be a thought leader in the field of student housing and to use this knowledge for the good of all students in the Netherlands. Because DUWO is the biggest social student housing association in the Netherlands, DUWO can be the initiator to work together with other student housing associations and to share knowledge.

6.2.1.5 DELIVERY MODEL

Traditionally, the design-bid-build (DBB) delivery model is used to arrange the building process (Kubba, 2012). The DBB delivery model is a linear process in which the client first selects an architect that prepares construction drawings and makes a design. After the drawings are finished the drawings are published for any contractor to bid on or a group of contractors is selected to bid on the project. The contractor will bid the amount for which they think they can build the building and most of the time the contractor with the cheapest bid is rewarded with the project. The disadvantage of this delivery model is that the contractor is not involved in the design of the building and therefore it is possible that the design is not efficient, cost effective or cannot be executed, requiring late changes to the design. With modular construction the installation concept, design details and connection method should be determined early on in- or even before the design phase (Hyun, Kim, Lee, Park, & Lee, 2020). This is needed to start the modular unit production as soon as the environmental permit has been granted and this will make sure that minimal reworks to the design are needed. Therefore, the modular manufacturer needs to be involved right at the start of the project. Based on interviews with interviewee S3, S6 and S7, the modular manufacturer should even be approached before the architect to be as cost efficient as possible. Currently just like with traditional construction, often the architect is contacted first to make a design for the building. This is however not efficient, because every modular system is different, and the design needs to be adapted to the modular system. Furthermore, according to interviewee S2, the installation concept is the most dictating and limiting factor in the design process. Therefore, it is also important that the company that makes these installations is already involved right from the beginning in the design process to make the building as cost efficient as possible. Because every modular system is different, the architect cannot make an optimum design for a modular building system that is determined once the preliminary design is already there. Furthermore, many modular manufacturers currently have a building configurator that can easily and effectively generate optimal building shapes that fit well with their modular system. This way the most cost effective and efficient building shape can be realised. According to interviewee S6, the role of the architect with modular construction is to make sure the building fits into the surrounding environment. Most modular manufacturers offer many different façade cladding options, which makes that the architect will be responsible for making a design for the façade appearance of the building. Furthermore, the architect will be responsible for safeguarding the requirements of DUWO and making sure the performance is according to the program of requirements. The architect will not be responsible for making the floorplans anymore, because this is already included in the modular system.

When the modular manufacturer has to be involved at the beginning of the project the traditional delivery model cannot be used. There are many other delivery models that can be used to involve the modular manufacturer at the beginning of the project such as the integrated delivery model design build (DB), construction management, early contractor involvement, and co-making. The use of the integrated delivery model for modular construction is a good option because most modular manufacturers are capable to do the whole construction process inhouse including the design. When using this delivery model, all the project risk is for the modular manufacturer, the only thing that DUWO would need to do is provide a program of requirements to the modular manufacturer (Chao-Duivis, 2018). This means however that DUWO does not have very much control over the project. Interviewee S3 proposed co-making as a good delivery model for realising modular buildings. With co-making a long-term relationship will be established between a few parties that is based on trust. This trust is established through financial transparency and information sharing. Establishing trust among the different involved party's costs money, time, and effort and therefore it is important to establish a long-term relationship. This connects well with chapter 6.2.1.3 in which was proposed that DUWO should contract a modular manufacturer for a few years to reduce building cost. The advantage that co-making can offer is that by working together problems can be overcome, which creates a win-win situation for all parties. The parties involved in the co-making team can vary and depend on what is important for DUWO. Parties that are important to involve in the co-making team for modular construction projects are the modular manufacturer, developer, architect, maintenance department, operations department, and the installation company, but also the user should be included. For co-making to be a success at the beginning of the project common goals will have to be established with clearly measurable KPI's to be able to evaluate the progress. Furthermore, to prevent conflicts about the work that needs to be done it is important to make a scope of work matrix at the beginning of the projects. In this scope of work matrix every party indicates their responsibility for the realisation of the project and this way tasks that fall out of scope can be divided and distributed among involved parties. This will prevent discussions about tasks that fall out of scope, and this will make sure all tasks are within scope of a party, which will reduce extra unforeseen cost.

6.2.1.6 BANK GUARANTEE

In the building sector in the Netherlands, it is common that the client asks for a bank guarantee of the party that executes the work (Verstegen, 2013). This bank guarantee is there to give the client financial insurance in case the executing party doesn't deliver the building to specification and covers the costs that must be made to make the building to specification. The use of a bank guarantee however has some negative effects for the executing party as well as for the client. The bank guarantee can put quite some restrictions on the available credit space of the executing party, which negatively affects their ability to use the money to innovate. According to interviewee S5 the bank guarantee requires about 5% of the entire building sum for modular construction. Furthermore, when an executing party is near bankruptcy the triggering of a bank guarantee without proper reason by the client can make the executing party go bankrupt. For the client the use of a bank guarantee will cost money because the cost of drawing up the bank guarantee and the cost for triggering the bank guarantee will be for the client. This shows that financial insurance for the client has quite some negative effects for both parties. Based on an interviewee S5, the bank guarantee puts restrictions on available funds, which can be used a lot better to invest in an automated production process or product innovation. According to interviewee S5, it made no sense to ask for a bank guarantee for modular construction, because the client pays when a module is finished, and this finished module can be seen as an entire finished product. With traditional construction many different stakeholders work together to eventually reach a finished building, so if one stakeholder would neglect his task it can cost the client a lot due to other stakeholders being delayed. Therefore, the bank guarantee made sense for traditional construction, but it doesn't anymore for modular construction. According to interviewee S5, if this bank guarantee isn't used anymore or if the amount is reduced, the cost of modular construction can be reduced. Interviewee S7 was asked if they thought this bank guarantee made sense for modular construction. They however indicated that it is in the best interest of the client to still have some certainty even though modular construction might involve less risk than with traditional construction. As discussed in chapter 4.2 there is a risk of the modular manufacturer going bankrupt, which could result in missing modules. These modules can also be made by another modular manufacturer, but this will require extra money and effort of the client. Therefore, it is still needed for the client to have some guarantee. Interviewee S7 proposed that also other agreements could be made that reduce the risk of the manufacturer not delivering, such as delaying payments by a few weeks or asking for a concern guarantee if the modular manufacturer is part of a bigger concern. It might not be possible to completely remove all financial guarantees for the client to reduce the building cost, but this indicates that DUWO should think differently when it comes to modular construction and that the old way of doing things might not always be the best way when using modular construction.

6.2.2 BUILDING SPEED

The increased building speed that modular construction can offer is according to interview S1 a major advantage of modular construction (see chapter 4.1). That modular construction is faster than traditional construction also showed from the building analysis in chapter 5.7.1, in which also was concluded that the performance of modular construction based on building speed is good. Despite that modular construction performs good on building speed, there are still a few points of improvement that were discovered through the interviews and case studies that were performed.

Interviewee B9 confirmed that the increased building speed of modular construction is an advantage for commercial developers, because most developers have to borrow money to realise a building, which means that over the period of construction they have to pay interest over this loan. DUWO pays an average of 3% interest over their entire portfolio, which means that the interest payments over the entire construction time can add up to a significant sum. Furthermore, the sooner the building is ready the sooner the building can be sold or rented out to get an income from the building, which gives again room to start a new project. Currently DUWO doesn't stimulate building speed, because the developers don't have to include the interest over the loan during the construction phase in their rentability calculations for projects. This gives the developers at DUWO no incentive to use modular construction to increase the building speed. DUWO should start incorporating this interest during the construction phase in their rentability calculations, because according to interviewee B9 in reality not stimulating construction speed costs DUWO quite a bit of money.

In the past DUWO has chosen to construct the façade using a traditional onsite method while the structure of the building was made using 3D modular construction. Because the façade was not finished in the factory, a scaffolding was needed to construct the façade, which greatly decreased the building speed. Therefore, when using modular construction, the façade should be already assembled in the factory to achieve the maximum building speed.

6.2.3 MAINTENANCE COST

Even though the modular buildings already perform quite well when it comes to maintenance cost, the aim should be to reduce this cost even more. Maintenance costs are important to consider when looking at the financial health of an organisation, because during the entire building lifetime the maintenance cost contribute a lot to the expenses of an organisation. When using a 50 year exploitation phase and using the goal that DUWO has for maintenance cost, the total maintenance cost over this period for building Hildebrandpad with 504 lettable rooms will be 18 million. The total construction cost for this building was 28.8 million as can be seen in table 6, which means that 63% of the initial construction cost is spent on maintenance. For the other buildings Uilenstede A+B, Laan van Spartaan and Uilenstede G+F this total maintenance cost to initial construction cost ratio is 52%, 73% and 54% respectively. This shows that quite a bit of money can be saved over the entire building life if the maintenance performance of modular buildings would be increased. According to interviewee B7 a lot of maintenance cost can be saved if the installations of the building would be better adapted to the building function. Currently with most buildings the contractor is responsible for delivering the entire building for the price that they gave during the procurement phase. The contractor hires a sub-contractor for the installations and the contractor tries to find the cheapest sub-contractor that can install the installations such as cooling and heating installations and elevators. This means that often the installations with the lowest initial cost are chosen and not much attention is paid to choosing the best installation considering the maintenance cost and the building function. An example of this was given by interviewee B7 who mentioned that the elevator and heating installation are used a lot more frequent than in normal apartment buildings, because students have no regular 9 to 5 workday and therefore the installations are used all day through. This more intense use of the installations is currently not considered when making a new building due to this cheapest initial construction cost mentality. Based on interviewee A2, to make sure that DUWO gets the best installations in their buildings, they have to describe the desired performance of the installations in their program of requirements. This may result in higher initial construction costs, but money can be saved over the entire building lifetime. This is just an example to illustrate that DUWO should not only pay attention to the initial building cost, but that the total cost of ownership (TCO) of the building should be considered to save money. In the chapter below recommendations will be given how TCO should be considered when designing a new building.

6.2.3.1 TOTAL COST OF OWNERSHIP CALCULATION

As has been elaborated upon in chapter 3.2.5, TCO is a financial management strategy that measures all the costs of the building during its complete life cycle, so that they can be managed and reduced as much as possible (APPA, 2016). To measure and reduce the building cost over its entire life, the developers, maintenance department and the operations department will have to work together. They have to work together to balance the initial building cost, maintenance cost, operating cost, refurbishment cost and demolishment cost over the entire life of the building, while considering the quality of the building (FMlink, n.d.). To be able to balance all these costs a TCO calculator can provide a solution for making all these costs visible, so that the different departments can make educated decisions. The overarching housing corporation Aedes has made a TCO tool that can help social housing associations that want to start with incorporating TCO in their calculations (Aedes, 2021). This tool gives insight in the affordability of an investment over a specific period of time, which housing associations can use to motivate a specific choice. This tool can be used throughout the whole construction and building exploitation process (Wereldstad, 2021). It can be used to make investments decisions to build a new building, which now are based on initial building costs and don’t consider maintenance costs. It can also serve as a contract agreement between the builder and client, in which the financial performance of the building is documented. And lastly it can be used during the exploitation phase to monitor all assets and to do performance measurements which can be used to further improve the TCO strategy.

By using a TCO tool, DUWO could save a lot of money over the entire building lifetime. To demonstrate that DUWO can save money by using a TCO approach, kitchen supplier Chainable was approached who have developed a kitchen with a low TCO (interviewee S4). They do this by using durable materials and making a separation between the lifetime of different elements in the kitchen just as discussed in chapter 3.2.3. By making this separation, they made sure that the elements with the lowest functional or technical lifetime can be easily replaced with a new material. This ensures that the kitchen elements that have a high functional and technical lifetime can stay in the room. Currently with a traditional kitchen these elements with a long lifetime are also removed because they are attached to the elements with a low lifetime. That only the elements with the lowest technical or functional lifetime are replaced is not only good for the environment, but it also saves money. This is because when the kitchen is at its end of life after 25 years, only parts of the kitchen must be replaced and not the whole kitchen. Chainable has made a TCO calculation for a standard DUWO kitchen for which the traditional price was known (see Appendix C: TCO calculation DUWO kitchen). In this TCO calculation only the renovation after 25 years has been considered and not the periodical maintenance or repairs. This TCO calculation showed that the Chainable kitchen is 16% cheaper than a traditional kitchen over a period of 50 years. Most parts of the kitchen last longer than 50 years, which means that if a longer exploitation phase would have been considered in the TCO calculation the cost reduction would be even more in favour of the Chainable kitchen. Furthermore, in the Chainable kitchen parts can be easily replaced, which means that also cost could be saved on kitchen repairs.

Even though this is a kitchen and not a whole building, the same principles that Chainable uses can be applied to the whole building, which most likely will result in higher initial costs, but also in a cost reduction over the entire building life. Based on an interview with the modular manufacturer MOOS, quite some modular manufacturers are already incorporating TCO in their products and they can deliver a TCO calculation for a building that is made with their modular system. However, not all modular manufacturers make TCO calculations and this is mainly because clients don't ask for it yet. The modular manufacturers that are already making TCO calculations do this according to what they think is right. This means that every modular manufacturer currently makes its own TCO calculation, because there is not yet one best way to use modular construction and therefore there is no one best way to calculate the TCO. For DUWO to compare different buildings and evaluate them based on a standard it is important that all buildings are calculated using the same TCO method. Therefore, the Aedes TCO tool is handy and DUWO should aim at using this tool for all buildings, but more importantly DUWO should aim at contracting a modular manufacturer that incorporates TCO in their modules.

6.2.3.2 PASSIVE DESIGN

Based on the analysis of the buildings in chapter 5.7, the installations contribute for about 55% of the total maintenance cost of the building including periodic and non-periodic maintenance. To reduce this maintenance cost, passive design should be considered, which requires a lot less cooling and heating installations. When using passive design, the goal is to achieve a high level of thermal comfort though the use of very little energy for space heating or cooling (Theumer, 2018). According to interviewee S7 it is possible to make a modular building passive even with the new BENG rules (see chapter 3.2.6), but this has to be taken into account as a design requirement at the start of the design process. According to interviewee A2 however, will it be quite hard to make student accommodations passive, mainly due to the TO_{juli} requirement in the BENG rule that prescribes that a building cannot be warmer than a set amount for a set duration in summer. It will be hard for student accommodations to comply with this TO_{juli} requirement, mainly because student rooms cannot easily use night ventilation to cool down the building. This is because the student rooms only have one openable window in the room and therefore no ventilation flow can be made. Despite that it might be hard to design a building for students that is fully passive, DUWO should aim at designing buildings that use as many passive house principles as possible, because the maintenance cost of the installations will be a lot lower if there are less installations required to heat and cool the building. Furthermore, when using passive design principles, the energy use of the building will be decreased drastically, which also saves money in energy bills. This is however currently only an advantage for the students as the reduced energy consumption is not valued yet in the "huurpuntensysteem" that is used to value the rent price for the social housing that DUWO provides.

To make the buildings passive, the heating and cooling energy use should be reduced as much as possible. This can be achieved by applying the passive house principles that include good thermal insulation, airtightness, ventilation with heat recovery, no thermal bridging and superior window insulation. As illustrated before, currently the biggest challenge is cooling the building. In all analysed buildings in chapter 5.7 that did not have mechanical cooling, overheating happened. This is because before BENG, no rules or standards were available, which could be used to check if a building is comfortable in the summer. Therefore, overheating in summer was not very often considered in a building design. With the introduction of the BENG rule overheating of buildings is not allowed to happen anymore and therefore it is a lot harder to keep the energy use of the building low, because often mechanical cooling is needed. This mechanical cooling uses a lot of energy, requires maintenance, costs a lot to install and has a bad impact on the environmental cost (MPG). Therefore, according to interviewee A1, designers should try to design a building that reduces overheating without the need of mechanical cooling. The analysed building Hildebrandpad in chapter 5.6.1 experienced a lot of overheating in summer and therefore a professional analysis by the advisor Nieman was made about what caused this overheating and solutions were provided to reduce this overheating (see chapter 5.7.4 thermal comfort). The recommendations that were done in that report are discussed below, including an extra recommendation that was based on an interview with interviewee A2.

Reduce direct sunlight

To reduce overheating, sun shading will always be needed, because direct sunlight provides a lot of energy. Possibilities of sun shading are the application of solar control glass, sunscreens, exterior horizontal blinds, light shelves, overhangs and dynamic sun shading systems. Furthermore, the windows should be made as small as possible. According to the building codes, the minimum amount of glass is 10% of the usable floor space. For this 10% only the window part that is above 600mm above floor level counts and therefore the window for the student room should not be below 600mm above floor level.

Night cooling

Because student rooms only have a window in one side of the room, the possibility to ventilate is very low. Therefore, it would help to be able to ventilate to the corridor, which creates an air flow that can be used to cool the building during the colder nights. This provides the possibility to cool down the building, which increases the thermal comfort in the summer. According to interviewee A2 night ventilation cooling contributes a lot for the TO_{juli} score and is therefore important to consider.

City heating

The city heating pipes run through the building and deliver their heat to a heat distribution system in the room. Even if no heating is used, the warm water still goes up to the room, which provides quite a bit of heat to the room. To reduce this heat the installation shafts should be better ventilated, and the pipes should be insulated more.

Phase shifting materials

The phase shift is defined in hours and shows how long it takes before the heat penetrates the material. To keep the building cool, this phase shift should be as long as possible to keep the warmth out of the building.

Often used insulation materials are glass-fibre and PIR insulation, which have a good insulation value, but don't perform so well when it comes to phase shifting. Traditionally a lot of concrete and stone was used to construct buildings, which are excellent for phase shifting, but especially with modular construction a lot of wood framing is used. Wood framing is light and mostly consists out of insulation, which makes it important that these insulation materials perform well at phase shifting. Therefore, insulation materials such as cellulose or Woodfibre should be used because these materials can keep the heat out of a building for 9 or 7,5 hours respectively. This is long enough to keep the heat out of the building during the hot days and cool down during the cold nights.

Besides materials that slow down the warmth penetration from the outside to the inside of the building there are also materials that can capture the heat during hot periods (day) and release this heat during colder periods (night). These materials can be programmed to a specific temperature above which they capture heat and below which they release this heat. This decreases the heat and cold shifts during a 24 hour period and makes that a building is always at the same temperature. According to interviewee A2 this technique is currently not used very often, because the building sector is slow at adapting new inventions, but this could have a big effect on the thermal comfort in the room.

6.3 SUSTAINABILITY

The goal of the EU and the Netherlands is to become a climate-neutral society by the end of 2050. To achieve this, the building sector should become circular, meaning that all materials will be reused. According to interviewee S7 a good rule for the reuse of materials will be that we should use a material for as long as it takes the earth to generate it. This means that we have to use wood for a minimum of 25 years, while we have to use concrete for millions of years. Based on this rule we have to limit the use of new virgin materials, but it will still be possible to use new materials, only in lesser amounts. As we approach 2050 the government will increase the rules to be able to achieve the goal of 2050. This can already be seen in the fact that buildings need to be nearly energy neutral with BENG, buildings can only use a set amount of polluting materials (MPG), and building projects that produced to much nitrogen were put to a stop a few years back. Based on interview S7 and other personal communications, a CO_2 tax could be next, in which money must be paid for the CO_2 that is emitted through the production of the material. Interviewee S7 even indicated that many big investors fear that CO_2 tax will have to be paid for materials that come out of existing buildings and therefore these investors are currently hesitant to build with concrete. Because of the very likely scenario that the Netherlands will become a circular economy and that penalty fees will have to be paid for buildings that are not circular, it would be beneficial for all building owners, including DUWO to already start preparing for this change. A climate neutral society also involves a strong reduction in the use of energy for buildings and the use of sustainable energy sources. Due to the new BENG rule, the Netherlands is well on track with reducing the energy need of buildings, but this energy use must be lowered even more. In chapter 6.2.3.2 passive design was discussed, which should be used to reduce the energy consumption to a minimum and therefore it will not be discussed in this chapter anymore. In the chapters below recommendations will be given on how DUWO can prepare for a future circular economy.

6.3.1 POSSIBILITY OF REUSE

As discussed above, if the Netherlands wants to become a climate-neutral society circularity and thus reuse of materials will be an important method to reach this goal. As discussed in chapter 4.1, a big advantage of modular construction is that the buildings can be disassembled, which provides the opportunity of reuse. Based on interviews with modular manufacturers and the building analysis in chapter 5.6 this is however not always true on the module level. It depends on the building height how well the modular units must be connected to each other. Up to three levels, the modules do not have to be connected to each other at all and only the force of gravity is enough to keep them in place. From three to eight storeys the modules will have to be connected, but this is generally not that hard and can be done with bolds and nuts. From eight storeys onward, the modules will have to be connected very well and therefore some manufacturers choose to connect the modules using concrete, which makes that this building cannot be disassembled anymore. On the building material level some modules can be disassembled better than other modules. Most modules can be disassembled into larger elements, which are floor, structure and infill. However, wet connections are still used to construct the module such as tiling, masonry and welding of the steel structure, which make that the modules cannot be disassembled that easy and not all materials can be reused. This shows that currently not all modular manufacturers aim to design for disassembly, mainly because the clients don't ask for it yet. Designing for disassembly could however have next to sustainability aspects quite a big advantage for DUWO, especially for the bathrooms. According to interview B9, bathrooms are typically very difficult and expensive to maintain and therefore modular bathrooms can be a solution. They can be replaced quickly, which could be beneficial for DUWO, because when renovating the building students only have to be replaced for a very short time, which will save DUWO a lot of money and give students less discomfort. Furthermore, easily accessible pipes and installations in a bathroom would also increase the ease of maintenance for DUWO. Currently DUWO doesn't include a material rest value into their financial calculations when they start a new project and therefore there is no incentive for the developers of DUWO to aim at making buildings that are designed for disassembly. They currently do not take rest value into account, because according to interview B9 it is too risky for DUWO, because they don't know how much they will get for these materials in the future. Due to the rising material prices and the technological developments in the field of recycling, used building materials are by many stakeholders not seen as waste anymore, but as materials that can be sold and reused. To be able to reuse the building materials, a material passport has to be made in which the amount, reusability, quality and reuse value of the materials is documented. The height of the reuse value depends on the material itself, the ease of disassembly and the amount of material that is available. In the material passport the total reuse value of the building is calculated based on reference prices for virgin materials, transportation cost and labour cost. According to (Gichuhi, 2013) materials account for about 70% of the total building cost, which means that there is a lot of potential value stored in the building of which a big share can be retrieved. To be able to retrieve the biggest amount of value that is stored in the building, during the design, the disassembly should already be considered. When designing for disassembly the use of wet irreversible connections should be avoided as much as possible and materials with a long technical life span should be used.

Deloitte has done research to the financial reuse value of buildings in which they determined that the reuse of materials has a positive effect on the cashflow of companies (Rau, et al., 2019). In this paragraph the financial benefits of reuse will be discussed that followed from this report from Deloitte. The first benefit, as indicated before, is that the reuse value of the materials can directly be considered in the financial calculations. Secondly, the potential reuse value that is stored in the material passport is a theoretical value and can only be determined accurately when the building is disassembled. However, the theoretical reuse value in the material passport can give a quite accurate estimation of the cost or income that can be generated when demolishing a building. Currently DUWO determines the demolishing cost based on an estimate, but this estimate is not that accurate and can be quite a bit lower or higher. This is not very efficient, because when the demolition cost is higher extra unforeseen money needs to be put into the building and if it is lower, this spare money could have been used for improving the building or realising another building. The third cashflow benefit for DUWO is the possibility of reusing their own materials from a disassembled building in new buildings. DUWO can do this, because they own most of their buildings themselves. This means that not only the material cost for the new building will be reduced, but there is possibly also a tax advantage because DUWO doesn't have to pay VAT over materials that are already owned by DUWO. As discussed in the introduction of the sustainability chapter, the fourth benefit reduces the future risk of the government requiring a CO_2 fee for the use of new virgin materials as well as for existing materials that come out of demolished buildings. This fee will not have to be paid for reused materials and therefore design for disassembly could benefit DUWO in long run. Therefore, to design for disassembly and reuse could very likely have a positive effect on the cashflow in the future.

In the rapport of Deloitte they also looked at the fiscal effects of a high reuse value of the building when the building is at its end of life (Rau, et al., 2019). In the report they indicate that a high reuse value can have negative consequences on the amount of tax that needs to be paid. There are multiple reasons for this tax increase. The first reason is that the rest value of a building that can be reused will be higher than that of a traditional building (Figure 21). This will probably represent itself in a higher resale value, which means that a higher transfer tax will have to be paid. Furthermore, the increased rest value means that the depreciation of a building will be less, which is negative for the income tax that needs to be paid. This is because the depreciation of a building can be deducted from the taxable income, meaning that less income tax needs to be paid. If a building gets sold before the end of life, this increased income tax does however gets compensated for the most part because the capital gain tax is lower. This is because the reversion basis to which the building is depreciated over time is higher that makes the capital gain lower over which the company needs to pay taxes. The second reason is that the building will be valued higher by the government (WOZ) if the rest value of the building is higher. This is disadvantageous for the building owner because the municipalities require taxes based on the value of the property. For social housing associations this increased building value does however also have an advantage, because this allows them to ask more rent.

As discussed above, designing for disassembly results in a reuse value instead of a negative value due to demolition cost. This reuse value has positive effects for the cashflow, but results in negative fiscal effects, because more taxes will have to be paid. According to Deloitte however the negative fiscal effects don't way up to the increased cashflow that can be generated, but the fiscal effects have a negative effect on designing for disassembly (Rau, et al., 2019). Next to the advantage of increased cashflow, designing for disassembly also makes the building more futureproof in the light of increasing environmental regulation when approaching 2050. On top of this the building becomes more flexible, which reduces the risk of structural vacancy, because the building function can be changed more easily. Therefore, DUWO should steer on making buildings that are designed for disassembly. DUWO can do this by writing this requirement in their performance-based program of requirements and requiring a material passport from the modular manufacturer that DUWO can use to manage the reuse value themselves. Especially for modular construction this material passport can be made quite easily because modular construction involves standardisation, which means that for the most part of the building the same materials will be used. If it is not possible for DUWO to manage the value of these materials themselves, most modular manufacturers can offer a buyback guarantee

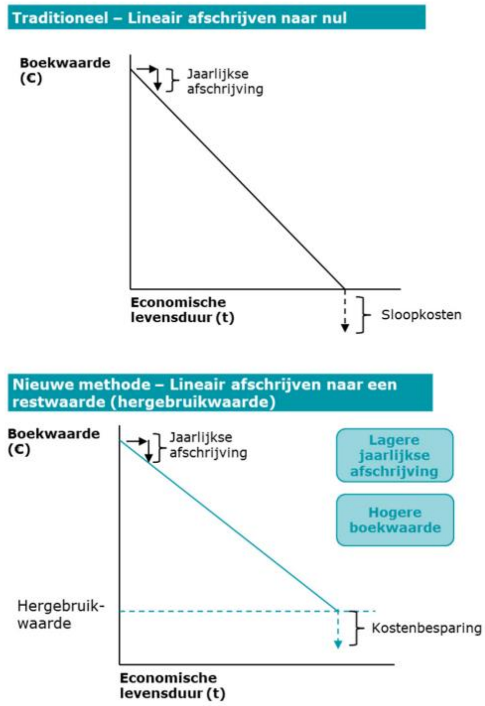


Figure 21: Depreciation traditional and reusable building adapted from (Rau, et al., 2019)

in which they can specify upfront how much they will pay for the modules when the building is at its end of life. This is however less beneficial for DUWO, because as mentioned before if they keep the materials in their own possession, they can use them for another building without having to pay taxes over the materials. Furthermore, according to interviewee S7 this buyback guarantee that modular manufacturers offer is only about 5 to 10% of the initial construction cost and therefore it would also be more beneficial for DUWO to manage the reuse value themselves.

6.3.2 BUILDING LIFETIME

As discussed in chapter 5.7.2 under the header building lifetime, many social housing corporations currently work with an exploitation period of 50 years. According to interviewee B7, they do this because they believe that at the end of this 50 years, the building needs a big renovation which will cost about the same as the initial construction cost due to increasing requirements in the building code. This 50 years however, limits DUWO at looking beyond this 50 years, which is important, because generally buildings are used longer than 50 years. For DUWO this 50 year exploitation phase involves multiple renovation cycli, which are according to the periodic maintenance plan for the building Uilenstede A+B: 30 years for the bathroom and kitchen, 40 years for the roof, 24 years for the ventilation installation and 20 years for the heating installation. Based on this data can be seen that different building elements have a different lifetime. As discussed in chapter 3.2.3, the different building elements can be grouped in different building layers according to the searing layer model of Frank Duffy (see figure 5). There is a difference between functional and technical lifetime and in chapter 3.2.3 was said that these generally don't match. This means that building elements that belong to a specific layer are replaced before they are at the end of their technical lifetime, because the functional lifetime is shorter. For DUWO however, this is for most layers not true as according to interviewee B6, DUWO replaces them only when it is technically necessary. This is for example the case with bathrooms and kitchens, but also with installations and the roof. The building structure and the façade cladding are not included in this periodic maintenance plan and therefore DUWO estimates that they last longer than this 50 years. If DUWO would assume a longer exploitation phase that is as long as the technical lifetime of the structure of the building, a better estimation can be made about the actual total cost of ownership as discussed in chapter 6.2.3.1. This would stimulate different material choices, but also provide more future oriented thinking. This future oriented thinking would incorporate how long the building structure will actually be used instead of assuming 50 years, which is in most cases not true. Based on interviewee S7, a longer building lifetime together with total cost of ownership thinking will force designers to think ahead, which should lead to flexible buildings that are futureproof. This can be achieved through design for disassembly as was discussed in chapter 6.3.1, but also the building structure should be designed flexible, which will be discussed in the next chapter.

6.3.3 FLEXIBILITY

As described in chapter 3.2.4, building flexibility is the ability to change the infill without having to make changes to the structure of the building. By incorporating flexibility in the modules, the building can change, which reduces the chance of permanent vacancy of the building. This is because if the building function can change there is no reason for the building to be vacant. Most buildings that are currently build are not very flexible. This shows in the structural vacancy numbers of the Netherlands, which are according to CBS (2021) currently 6.7% for offices and 6.2% for stores, compared to the average structural vacancy of 2,8%. This shows that there are currently too many offices and stores, which cannot be used for another function that has more demand. If these buildings would have been more flexible the function could have been changed to another function with more demand, such as housing. The future is unsure and therefore over a long period it could be possible that the preference of students has changed or that there is a surplus of student rooms, making DUWO buildings redundant. To make the buildings of DUWO more futureproof, the buildings should be made flexible. This can be done by allowing change to the infill of the building. A DUWO building consists out of relatively small rooms, which means that the building cannot easily accommodate another function without making changes to the interior. Therefore, it is important that the interior walls can be replaced and removed to some extent. The DUWO buildings that were constructed using traditional techniques often used concrete tunnelling with a width of 7400mm. This concrete tunnel was separated in two rooms of 3500mm with a wood framing wall, which means that these rooms could easily be joined again into a bigger room. However, it is not easily possible to go beyond this 7400mm due to the solid concrete wall from the tunnel. With modular construction many modules use a steel or concrete structure with columns, which are closed with a wood framing infill. These modules offer quite some flexibility, because when the wood framing would be removed, it is possible to create a big open space. There will however be braces in between some columns, but most modules will not have these, offering the possibility to change the layout of the building quite easily. There are however also modules that are made using cross laminated timber (CLT) for the structural walls. Because these CLT walls are structural, it is not possible to remove them, meaning that the layout of the building will be very inflexible. When deciding for modular construction the flexibility of the modules should be considered to make the building stock more futureproof. Based on interviews with multiple employees of DUWO it is very difficult to incorporate flexibility into the building, because it often requires an extra investment of which it is very unsure that this investment will be earned back.

Another aspect of flexibility is to over dimension the building structure. Based on interviews with DUWO employees, DUWO generally does not demolish their buildings in 50 years, but they can last for as long as they can fulfil their purpose. This can be a very long time and in this time it is possible that rules about building height have changed or that there is just more of a need to build higher due to a lack of building space. Team SUM of the TU Delft is a great example of this because they use the over dimensioning of the tenant flats that were built to add extra building layers on top of the existing flats. This is possible, because the columns and the foundation of the buildings are over dimensioned by accident due to a lack of rules in the past. Now this provides the perfect opportunity to not have to demolish the buildings, but to make renovation feasible including a top-up. DUWO should over dimension their buildings so that they can add a few storeys to the building in the future to deal with the uncertainty of future demand and rules. Often structural walls are already oversized in buildings, because of the noise reduction requirement. This resulted out of the analysis of the traditional building Uilenstede G+F in which walls of 250mm were used for the lower part of six storeys as well as for the tall part of thirteen storeys. Because modular units often use structural columns, this oversizing is not used, because it will cost extra money and use extra material. When designing for disassembly as illustrated in chapter 6.3.1 and incorporating TCO in the financial calculations, this increased cost should not be an issue for DUWO, because this extra money will be earned back when the building is at the end of its technical life. Therefore, DUWO should aim at oversizing the structure of the modules.

6.4 STUDENT SATISFACTION

Despite that financial health and sustainability are important objectives, the satisfaction of the people that are going to use the modules is also very important to consider. To test this, a survey was sent out under students living in a modular building and students living in a traditional building. In this survey questions were asked about the thermal comfort, ease of maintenance, acoustic comfort, and the satisfaction of the student in general with their room. This resulted in a few underperforming building aspects and therefore will be discussed below.

6.4.1 THERMAL COMFORT

As discussed in chapter 5.7.4 many students indicate that the building becomes too hot in summer. This is a known problem of student housing that was built before the BENG rule was implemented. Especially modular buildings experience overheating, because they generally use a lighter building structure which doesn't accumulate warmth very well. With the implementation of the BENG rule, also the requirement of the TO_{juli} was implemented which gives a maximum internal temperature of the building which cannot be passed (see chapter 3.2.6). There are many solutions for reducing the internal temperature of a building, but currently often mechanical cooling is used to cool the building. This is not beneficial for the energy use of the building, and it requires an extra initial investment and requires a lot of maintenance. Therefore, as discussed in chapter 6.2.3.2, the principles of passive design should be used when designing a modular building.

6.4.2 ACCOUSTIC COMFORT

For students acoustic comfort is especially important, because students often have people over in their room and they generally make quite a bit of noise. Students also use their room to study and sleep, and therefore the sound between the different rooms should be reduced as much as possible. Based on the survey there were no complaints about acoustic discomfort that was caused because the walls and floors did not reduce the noise enough. The only complaint was that the building was close to the airport and therefore students experienced acoustic discomfort, which should be considered if new buildings will be built close to an airport. Based on an interview with modular manufacturers S3 and S6, modular construction performs better than traditional construction in noise reduction due to the double layers that are used. These double layers come from the fact that 3D modules are placed next to each other, which gives double walls, and that modules are placed on top of each other which gives a separate ceiling and a floor. Most modular manufacturers that were interviewed use concrete for the floor to reduce the noise between the stacked modules. Only interviewee S7 uses wood for the floor, and he indicated that they reach the same noise reduction as other manufacturers that use concrete. This shows that modular construction performs very well on the field of acoustic comfort, but it would be good for DUWO to request acoustic reports from the modular manufacturers, which really can back up these claims.

6.4.3 EASE OF MAINTENANCE

Based on the analysis in chapter 5.7.4, the main issue when it comes to ease of maintenance are the small tiles in the bathrooms and kitchen. These tiles have many grouts that get dirty and are hard to clean. Based on interviews with modular manufacturer S2 and S5, the bathrooms can be made easier to maintain if High Pressure Laminate (HPL) sheets would be used for the bathrooms and kitchens to replace tiling. These sheets can have all kinds of different prints on them and what I have seen in the prototype of team SUM, they can even be indistinguishable from tiling. The sheets can be as big as 4279x2130mm, which greatly increases the construction speed and reduces the number of seams in a bathroom compared to traditional tiling. As a result of the decreased amount of seams, the bathroom walls will be easy to maintain, and the construction cost can be lowered due to faster construction. The floor tiling could be replaced by many different materials such as HPL sheets, vinyl, PVC and even waterproof HDF laminate floors. According to interviewee S2, the use of these new materials will greatly increase the appearance of the bathrooms, giving them a more luxury appearance. Therefore, DUWO should replace the traditional tiling with other materials such as HPL sheets that have minimal seams and are therefore easy to maintain.

7 CONCLUSION

In this chapter the results of this graduation research will be presented by answering the main question. The following main question has been used for this research: ***"What is the current performance of 3D modular multistorey student accommodations in the Netherlands and how can this performance be increased?".***
This main question will be answered by first answering the sub-questions that will lead to answering the main question.

7.1 Q1

The first sub-question is: *"What is modular construction?"*. This sub-question is very important to understand this graduation research, because in literature and in practice there are many different definitions of modular construction. Based on literature, modular construction involves separate parts that are constructed in a factory and standardisation. Often the standardisation aspect of modular construction is forgotten in definitions that can be found in literature and in practice, but this standardisation is key to realise the advantages of modular construction. If the standardisation aspect is not included, it cannot be called modular construction, but the right term is prefabrication. Therefore, the definition that is used in this research is: "modular construction involves producing standardized modules of a structure in an off-site factory, after which they are assembled on-site".
Based on this definition there are still many different types of modular construction, but this research focused only on one type of modular construction. There are three main types of modular construction which are 1D, 2D and 3D modular construction. 1D modular construction are standardized components such as bricks and doorframes, which are the lowest level of modular construction. 2D modular construction is also called non-volumetric construction, which are building elements such as complete walls, floors, and roofs. 3D modular construction is called volumetric modular construction, and these modules are the highest level, because it encloses an entire space such as a bathroom, bedroom or living room. In this research the focus has been on 3D modular construction because construction speed wise this is the most efficient form of modular construction.
Standardisation is very important for the advantages of modular construction, because through repetition a more efficient working process can be realised. Therefore, standardisation should be implemented well beyond individual large projects so that industrialisation of the building sector becomes possible. This can be achieved through standard size increments in which the modules can be scaled up, standardized detailing, and standardized processes. Currently many modular manufacturers use closed industrialisation, which means that they standardise their modules for the use of one building function. The ultimate goal however would be to focus on open industrialisation in which standardised modules can be used for multiple building functions. This research however focused on closed industrialisation.

7.2 Q2

The second sub-question is *"What are the advantages and obstructions of modular construction?".* Through answering this question will become clear why modular construction should be used and what is still hindering the uptake of modular construction.

Advantages
According to literature and market research, modular construction has a lot of advantages over traditional construction. In this research the advantages have been interpreted from the perspective of the developer, investor or client and do not necessarily have to be advantages for all stakeholders involved in the construction process. An important reason why modular construction is chosen is that the construction period can be shortened by up to 50% due to fast-tracking. This is the possibility to let multiple processes happen at the same time, such as when the foundation of the building is made, the modules are also already made. This reduced

construction time is beneficial because this means an earlier income from the building. Another advantage of modular construction is that it has some sustainability benefits such as reusability of materials due to the possibility of disassembly, reduced waste production and reduced transportation movements. These benefits are getting more important with increasing environmental regulation as we are approaching the goal of the Netherlands to become a climate-neutral society in 2050. Another advantage is the reduced construction cost that modular construction can offer. This reduced construction cost can be up to 24% compared to traditional construction, but for most projects, currently 10% is reasonable. The height of the decreased cost mostly depends on the amount of standardisation that is implemented in the building. Furthermore, modular construction offers the advantage of reduced traditional trade labour. Modular construction requires less traditional labour, because due to standardised processes, traditional trade labour can be replaced by robots. The labour costs have been rising due to labour shortages and therefore the reduced need of traditional trade labour can reduce the construction cost. What also has an impact on the construction cost is that modular construction offers a reduced failure cost. This is possible, because due to standardisation the wheel does not have to be reinvented every time and therefore the modular manufacturer can learn from previous projects. Furthermore, because the modules are made in the controlled environment of a factory, the building quality is also a lot higher. This is mainly noticeable due to increased thermal performance and acoustic performance, because of decreased tolerances and a double layer construction. Furthermore, because most of the work is done in the safe environment of the factory, the safety of the workers is increased. Also due to the factory, there is less disturbance for surrounding buildings, which can be a great advantage in inner city construction sites.

Obstructions

Despite the many advantages that modular construction offers, adoption has been low. This is because the construction industry in general is unfamiliar and not confident with implementing modular construction. This is because every stakeholder that is involved in the construction process experiences obstructions that holds them back on using modular construction more frequently. An obstruction that is experienced by many different stakeholders is that there are misconceptions from the past about modular construction such as bad aesthetics and decreased structural safety. This holds them back from using modular construction. Another obstruction is that collaboration in the building sector is low, mainly due to the separation between the design and construction phase. This is mainly caused by the traditional design-bid-built delivery model in which first the architect makes the design and after which the contractor executes the design. This causes a bad integration of modular construction in the design, because all modular manufacturers have their own system and therefore modular construction is often replaced by traditional construction during execution. The building sector can be divided in three groups when it comes to obstructions to use modular construction. These three groups are buyers (developer, client, investor), suppliers (architect, modular manufacturer, contractor), and government.

An obstruction for the buyers is that in the current organisational structure of most companies, is split in different branches that don’t communicate very well with each other. To implement modular construction well, at start of the project other branches should be involved in as well to make the building as efficient as possible. Currently the separation of branches is a great obstruction for implementing total cost of ownership, which should be looked at when implementing modular construction the right way. Furthermore, due to the standardisation of modular construction, the shape of the building plot could not fit with the shape or size increments of the modules. This would mean that the developers can realise fewer square meters with modular construction and therefore they will earn less money on the project. Also, the level height is a bit higher than with traditional construction due to double layers of the floor and ceiling, which can be an obstruction for developers. If there are height restrictions on the plot, this higher level hight means that one less storey can be realised, which equals fewer square meters. An obstruction for clients is that no late changes can be made to the building design anymore, without major consequences to the building schedule and budget. This is because with modular construction very early on in the project the design needs to be finalised, because the construction of the modules starts already. An obstruction for the investor is that there is a risk of the manufacturer failing to deliver, which creates risks in the project delivery time, budget, and quality of the building. This is a big risk, because with traditional construction it is relatively easy to find a replacement contractor, but modular construction is very specific and therefore it is difficult to find a modular manufacturer that can finish the work.

For the suppliers an obstruction is that a modular factory requires very high initial capital (50-100 million) to set up a manufacturing plant for the production of the modules. Related to this is that due to the lack of modular factories, the average distance between the construction-site and the factory is quite big. This distance is an obstruction, because if the distance is too big the transportation cost will be too much, and the project will not be feasible. Furthermore, this big distance brings the risk of late delivery and because with modular construction just-in-time delivery is important this can be an obstruction for the expansion of the use of modular construction. The last obstruction is that there is a lack of design guidelines for architects to design with modular construction. If the designers start designing without these guidelines the building design will not be efficient, because it will not fit with a specific modular system.

The last stakeholder group involved is the government. This stakeholder has no direct obstruction for the implementation of modular construction, but the government could stimulate the use of modular construction more through incentive and mandatory policies.

7.3 Q3

The third question measures the performance of the modular student accommodations that have already been built by DUWO. The following sub-question is used for this performance measurement: *"to what extent can modular construction currently satisfy the expectations of student housing associations in the Netherlands?".*

Performance is a very subjective topic, because it is dependent on the culture and preferences of people. With this is meant that performance is the capability of something to meet certain objectives. In this report important objectives of the built environment and DUWO have been considered. This resulted in five main objectives, which are: financial health, sustainability, affordability, student satisfaction and student wellbeing. To measure these objectives, the objectives have been split into key performance indicators (KPI). These KPI's have been used to measure the performance of three modular buildings. To measure this performance, the building data has been ordered in a comparison table per KPI, after which the data was analysed through interviews and supplementary building data. For every KPI a goal was established based on DUWO goals, but also on goals of the government. This goal was compared with the measured data of the buildings to determine the performance of the specific building aspect.
In the table below the results of the performance measurement can be seen. This shows that there are many building aspects that perform less than good, which means that these things need to change in newbuilt modular buildings to increase the performance.

Objective	KPI	Performance	Definition of performance
Financial health	Building speed	Medium	The building speed performs better than the traditional building, but for most buildings some façade finish still needed to be done on site, which makes that the building speed can be increased and therefore the performance is set to medium
	Construction cost	Medium	The older buildings perform less, while the new modular building performs good, therefore the performance is set to medium
	Maintenance cost	Medium	The modular buildings perform better than the traditional building and better than the goal. However, the trend is that the maintenance cost will rise over time and therefore the buildings perform medium on the maintenance cost
Sustainability	Insulation value	-	Cannot be said due to changing regulations and standards
	Heating and cooling energy use	-	
	Renewable energy share	-	
	Building lifetime	Insufficient	DUWO uses an exploitation phase of 50 years, which makes no sense for all building parts, which results in insufficient performance
	Possibility of reuse	Medium	Not all buildings can be disassembled and buildings that can be disassembled can only be disassembled on the building sector cell level (see chapter 3.1.1)
Affordability	Service cost	-	Cannot be said due to changing regulations and standards
	Rent price	Good	Is related to the financial health of DUWO, but considering that DUWO achieves their ambitious goal the performance is set to good
Student satisfaction	Thermal comfort	Medium	The buildings perform well in well in winter, but in summer the buildings overheat
	Acoustic comfort	Good	The building performs good, the only complaint is that the building is situated close to the airport and there is some sound disturbance at the top floor
	Ease of maintenance	Medium	Mainly the bathroom is not easy to clean due to small tiles and many grouts
	Room size	Good	The analysed buildings have big rooms that are well above the standard
Student wellbeing	Fire safety	Medium	Building complies with building codes, but students feel not safe
	Size of common rooms	Insufficient	There are no common rooms in the analysed buildings

7.4 Q4

In this last sub-question has been looked at how the bad performing elements from the previous sub-question can be increased. This is done using the following sub-question: *"how can the performance of modular construction for student accommodations in the Netherlands be increased?".*

To answer this question, recommendations are given to increase the performance of modular student accommodations in the Netherlands. These recommendations are made through interviews with professional stakeholders that have experience with modular construction. These recommendations are not given for every KPI of which the performance was measured. For the KPI's that fall under the objectives affordability and student wellbeing no recommendations could be given to increase the performance. This was not possible, because this performance was already solved in the new buildings of DUWO or no direct performance improvement could be made through modular construction. This means that only the objectives financial health, sustainability and student satisfaction have been thoroughly discussed and recommendations for improvement have been presented. The recommendations that are given are aimed at DUWO, but they can also be used for other similar organisations.

Financial health

The financial health is one of the most important objectives for companies, because this makes sure that they can keep performing their task. Therefore, it was important to look at the construction cost, maintenance cost and the building speed and give recommendations to improve the performance of these building aspects.

To improve the performance of modular construction on the building cost aspect, the initial cost should be reduced. The first recommendation that was given is to increase the standardisation by using a standardised building system that DUWO can develop themselves, or they can use a standard building system that is already available in the market. This will ensure that mass production becomes possible, which greatly reduces the construction price of the modules. To achieve this standard, a performance-based program of requirements should be made. This will make sure DUWO gets what is important for them and it leaves room for the manufacturer to be innovative and cost efficient. Especially if DUWO is going to use a standard that is in the market, a performance-based program of requirements is important, because with a specific program of requirements the standards of the modular manufacturers will have to be changed, which increases the cost. Because every modular manufacturer has their own standard, it would make sense for DUWO to make a purchasing agreement with one or two modular manufacturers. In this purchasing agreement DUWO will commit to buy a specific number of modules over a specific time period. This will not only provide with a more uniform product over all DUWO buildings, but it will also be cheaper for DUWO to do this. This is because for a modular factory continuity is very important and with this contract there is less risk of downtime for the factory, which makes that the modular manufacturer is willing to give a discount. To make this contract even more feasible, DUWO should start working together with other student housing associations to be able to buy even bigger amounts of modules. DUWO can do this, because they are part of the overarching student housing association Kences and they are by far the biggest housing association of Kences. Furthermore, to reduce the building cost, a different delivery model should be used than with traditional construction. With traditional construction, often a design-bid-built model is used. This makes that the design and construction are separate, and that the contractor is not involved in the design. With modular construction early involvement of the modular manufacturer is key to make an efficient building design. Therefore, the modular manufacturer should be approached before or at the same time as the architect, so that the architect can make a design that fits with the modular system. Lastly, DUWO should start rethinking if what has always been done is still the best way with modular construction. Traditionally a bank guarantee is put in place, which guarantees that the client will get money in the case that the contractor fails to deliver. With modular construction this bank guarantee is still used, even though there is much less risk of a stakeholder failing to deliver as the modular manufacturer delivers a finished product. There is still the possibility of the modular manufacturer going bankrupt and therefore there should still be a financial guarantee for the client in place, but this could also be arranged differently. For example, DUWO could delay payments, or a concern guarantee could be asked for. This would be beneficial for the modular manufacturer, because a bank guarantee requires a lot of capital of the manufacturer which could be better spend on innovation. Therefore, if DUWO would not ask for a bank guarantee, but uses a different financial guarantee, the modular manufacturer could possibly reduce the building cost. This bank guarantee was only an example, but the same is true for many other building aspects such as the program of requirement, financial calculations and procurement.

Another aspect that influences the financial health of an organisation that exploits buildings is the maintenance cost of a building. This maintenance cost should be considered when designing a building. Therefore, DUWO should make a total cost of ownership (TCO) calculation in which the actual cost of the building is determined over its entire life. To measure and reduce the building cost over its entire life, the developers, maintenance department and the operations department will have to work together. They have to work together to balance the initial building cost, maintenance cost, operating cost, refurbishment cost and demolishment cost over the entire life of the building, while considering the quality of the building. A TCO calculator can be used to visualise the entire building cost, on which decisions can be based. To reduce the TCO as much as possible, DUWO should use passive design principles. With passive design the energy use of the building is reduced to a minimum. This means that the energy cost of the building will be reduced, which also has an impact on the affordability of the rooms for students, but it will also have an impact on the maintenance cost of installations. This is because no or very little cooling and heating installations will be needed, which normally require the highest maintenance costs.

Lastly the building speed should be increased, because this ensures a sooner income from the building and it reduces the rent that has to be paid during the construction phase. Modular construction is already a lot faster than traditional construction due to fast tracking, but there are some aspects that should be considered when designing the building. The main element that determines the construction speed of modular buildings is the façade. Mainly if a scaffolding is needed to construct the façade, the construction time is significantly increased. Therefore, when designing the façade DUWO should ensure that the façade can be fully finished in the factory to achieve the maximum building speed.

Sustainability

Sustainability has and will become more important as we approach 2050 in which the Netherlands should be a climate neutral society. Next to reducing the energy consumption of buildings, which is currently done through the BENG regulation, the use of new virgin materials should also be reduced. Therefore, a circular economy should be stimulated in which materials are reused. Modular construction has the advantage that the buildings can be disassembled relatively easy on the module level. This means that the modules can be taken out of the building, because no wet connections are used. Because the future is uncertain and there is no way of knowing if the modules are usable in the future, this is not enough. Therefore, the modules should become disassemblable on the element level, meaning that no wet connections are used to construct the modules. Many modular manufacturers don't do this yet because clients don't ask for this yet. Therefore, DUWO should specify this in their performance-based program of requirements. This does not only have sustainability benefits, but also financial benefits for DUWO. The financial benefits for DUWO are that their cashflow will increase due to the reuse value of the materials and the benefit of not having to pay VAT over already owned materials. Furthermore, it reduces the risk of future government policies for which money will have to be paid for demolishing and not reusing materials. There are however also some fiscal disadvantages of reusing materials, but the advantages outweigh the fiscal disadvantages. To make sure that fewer virgin materials are used in the first place, the lifetime of the building should be increased. Currently a common exploitation phase which is used to depreciate a building is 50 years. This means that during construction this 50 years is assumed as well, which makes that people don't look beyond this 50 years, even though buildings are often used longer than 50 years. Different building parts have different lifetimes. Many are shorter than this 50 years, but the structure and the façade have a longer lifetime. This means that these building parts are currently not considered beyond 50 years. This means that for example flexibility of the building is not considered that important, because people think that in 50 years nothing is going to change. If the real, technical lifetime of the building structure is assumed, this flexibility would become a lot more important, because it combats uncertainty. With flexibility is meant the ability to change the infill of a building without having to make changes to the structure. If this is possible, the building structure can stay functional even if the requirements of people change, which ensures a longer building life and thus a reduced need for new materials. Flexibility can be implemented in buildings by ensuring that the building walls can be removed through the use of a column beam building structure. Furthermore, the over dimensioning of structural elements ensures flexibility, because the modules can later on be used again for taller buildings or extra storeys can be added to the existing building in the future. Because with flexibility the buildings can be changed, design for disassembly is also very important.

Student satisfaction

Despite that financial health and sustainability are important objectives, the satisfaction of the people that are going to use the modules is also very important to consider. For the satisfaction of students, the thermal comfort, acoustic comfort and the ease of maintenance is important. For the thermal comfort, the most important thing in student buildings is cooling in the summer. This resulted from a survey that was done among students that live in a DUWO building. This cooling can be achieved through mechanical cooling, but to reduce the energy consumption and the maintenance cost, principles of passive design should be used to reduce the cooling need in the building.

Furthermore, according to the survey, the acoustic comfort of modular student accommodations is good. This is because of the double layers that are used with 3D modular construction, which result from double walls and the separation of the ceiling from the floor. That 3D modular construction performs better than traditional construction acoustically was confirmed by modular manufacturers, but these claims should be tested to be able to really back up these claims.

Lastly, the ease of maintenance is important, because this will make sure that building elements last longer and reduce the cleaning effort of the student. The main part of the room that is currently difficult to clean is the bathroom and the kitchen. Mainly the grouts between the small tiles are difficult to clean and therefore tiles should be replaced with a material that is easier to clean and maintain. A solution could be to use high pressure laminate sheets, which have very little seems and due to the size, the labour is reduced, which causes that the construction cost can be lowered.

7.5 MAIN QUESTION

The goal of this research was to gain insight into the performance of modular construction and to increase this performance. With this increased performance, the aim is to increase the uptake of modular construction and thus to realise all the benefits of modular construction. This increased performance can cause an increased uptake of modular construction, because through the performance increase, obstructions for developers can be decreased and advantages increased. The following main question formed the basis to do this research: ***"What** is the current performance of 3D modular multistorey student accommodations in the Netherlands and how can this performance be increased?".*

In the previous chapters all aspects of this main question have already been answered, which also form the answer to this main question. However, a very short conclusion will now follow. Modular student accommodations perform well compared to traditional construction but compared to the goals of DUWO and the built environment, the performance should be increased. Therefore, the performance of the construction cost, building speed, maintenance cost, reusability, building lifetime, thermal comfort and ease of maintenance should be increased. To do this, DUWO needs to change their way of thinking about finances, sustainability, collaboration, and project delivery.

7.6 DUWO

At the very start of this research was indicated through personal communication with interviewee B5 that DUWO was curious why modular construction is not used more often. Furthermore, they wanted to know how modular construction should be implemented in newbuilt buildings, what knowledge is currently available among modular manufacturers and how the program of requirements from DUWO fits with modular construction.
Through this research was discovered that the main reason why modular construction is not used more often is because there is a lack of knowledge about the advantages and obstructions of modular construction. From interviewee B1 who was also my graduation mentor, I have heard a few times that they would use modular construction more often if it was proven that it could reduce the building cost compared to traditional construction. Furthermore, if DUWO would be more aware of the other advantages that modular construction can offer, they would choose to use modular construction more often. This research provides a full list of advantages that modular construction can and therefore this research helps with making the choice for modular construction, of which the conclusion can be seen in subchapter 7.2. DUWO puts great value to the possibility of reduced construction cost with modular construction and they always assumed that modular construction reduces the building cost. This research proves them right, because based on interviews and case studies can be concluded that modular construction is cheaper than traditional construction if the façade is already installed in the factory. There are also some obstructions that hinder the use of modular construction. This research provided a full list of possible obstructions for different stakeholders that are involved in the construction process. The main obstruction for the use of modular construction from the perspective of the developer is that the standardised modules do not always fit with the shape or height restrictions of the building plot. This means that less square meters can be realised, which results in a reduced rentability for the developer. I noticed that DUWO employees try to make the decision themselves if they think that modular construction could fit this building plot or not. This is done based on a gut feeling and can therefore exclude modular construction while modular construction could be a valid option. Furthermore, if a modular manufacturer would be involved in this decision, they can indicate what the possibilities are for that building plot and possibly the building area defined by the municipality could be changed a bit. Also, according to interviewee S7, the combination of traditional construction with modular construction can solve this problem, while still realising the advantages of modular construction.

This research also looked at how modular construction should be implemented in newbuilt buildings, through giving recommendations. If modular construction is implemented properly, the advantages of modular construction can be increased while the obstructions can be decreased. Therefore, these recommendations help with increasing the use of modular construction. The conclusion of the recommendations can be found in sub-chapter 7.4.

8 DISCUSSION

In this chapter the results of this research will be discussed. This will be done by elaborating on the limitations to the extent of this research and by giving recommendations for further research.

8.1 LIMITATIONS

8.1.1 METHOD

The focus of this research has been on 3D modular construction and 2D modular construction was not considered. This excludes a big market, as in the Netherlands there are already quite a few modular factories that produce 2D modular building elements. The reason for only focussing on 3D volumetric modular construction and not on modular construction in general is that the advantages and obstructions for the use of modular construction are different for 2D than for 3D to some extent. This difference would also influence the recommendations that were given to increase the performance of modular construction. This would make this graduation research very extensive and double the number of interviews, building case studies, and literature research would have been required. Therefore, this research is limited to 3D modular construction for student accommodations in the Netherlands.

In this research the soil price has been excluded in the modular case study projects. This has been done, because the ground prices have no relation with the performance of modular buildings. This is however a limitation to this research as the ground prices are also a problem for the realisation of affordable buildings. This means that affordable buildings will be easier to realise in a small city compared to a big city. This limitation should be considered when reading this graduation research.

8.1.2 THEORETICAL REVIEW

Already a lot of literature has been written about modular construction in many different countries and different researchers use different definitions of modular construction. The type, country and extend of standardisation have an impact on the advantages, obstructions, and application of modular construction. This makes it difficult to know if the obstructions and advantages or the applications that are found in literature are also applicable to 3D modular construction. Most papers however already assume 3D modular construction if they write about modular construction, but nevertheless it might be possible that the advantages and obstructions found in literature are less or more intense when the standardisation or country is different.

In literature modular construction is seen as the solution to increase the building speed, reduce the building cost and make the building sector more sustainable. This are all positive aspects of modular construction, but there might also be negative consequences to the built environment if the use of modular construction is scaled up. These consequences might be repetition of mistakes, more material use due to double layers, transportation hinder, and other negative consequences. In this graduation research, these consequences have not been considered, which are however quite important to consider before modular construction is used more. If the negative consequences would already be known before mass use of modular construction, these negative consequences can be combated and reduced as much as possible.

8.1.3 EMPIRICAL RESEARCH

To measure the current performance of 3D modular student accommodations that have been built by DUWO, 3 modular buildings have been used. These modular buildings however are all quite similar because they are all build by the same modular manufacturer. Therefore, the performance measurement is limited to the product of one modular manufacturer, which does not represent all of the Netherlands. The analysed buildings do however not differ that much from the products of most of the modular manufacturers, as most build using a concrete floor with a steel frame and a wooden infill. Two of the analysed buildings use this same system while one uses concrete columns instead of steel. There are however manufacturers that build complete wooden modules or concrete modules, and therefore can be said that this limitation should be considered when reading this graduation research.

Furthermore, there is a lot of innovation happening in the field of modular construction, which means that products change. The buildings that have been analysed range between 4 and 10 years old, which is not that old yet for buildings, but for modular buildings it is. The modular system that is used for the buildings up to eight storeys is still used, but the performance of newer modules has changed compared to the old modules. Therefore, when talking about the current performance, the performance of 4 to 10 years ago is meant. This means that this performance measurement is limited because it is not very up to date.

In the chapter about performance improvement, recommendations are given to increase the performance of modular construction for student accommodations. These recommendations are based on interviews with six modular manufacturers and two advisors. The recommendations are validated through the interviews, but as only so many interviews could be done, more validation of the recommendations could be required to be able to implement the recommendations with confidence. Furthermore, the recommendations will have to be reviewed by more DUWO employees. Now only interviewee B1 and B5 have reviewed the recommendations and they thought that most recommendations were feasible to implement and that they provided something to think about. During the writing of the recommendations also some other DUWO employees have been asked for the feasibility of specific recommendations, but this could have been done to more employees. Therefore, this research is limited to a select group of DUWO employees that has looked at all or a few recommendations, which means that some disciplines within DUWO could see problems regarding some recommendations.

8.2 RECCOMENDATIONS FOR FUTURE RESEARCH

In this graduation research, recommendations were made to improve the performance of 3D modular construction for student accommodations in the Netherlands. These recommendations alone do not change the performance of modular construction. What is important to increase this performance is that these recommendations can get implemented in the policy and work method of a company. This means that more research will need to be done to execute the recommendations. For example, a recommendation was that DUWO should work together with other housing associations. To make this happen research will need to be done to see how they could work together to be able to make a contract with modular manufacturers, so that modules can be acquired cheaper. Another example is that to implement total cost of ownership (TCO) in the financial calculations DUWO will have to make a lot of changes in the way they calculate buildings, but also in the way that they work. To implement TCO in the projects, the organisational structure as elaborated upon in chapter 4.2 will need to change. Therefore, a lot of research will need to be done on how to implement TCO. A recommendation that was done is that DUWO should make a performance-based program of requirements to be able to trigger innovation from the modular manufacturer and to be able to use the standards that are already in the market. According to personal communication with interviewee B3 it is a lot harder to make a performance-based program of requirements than it is to make a normal program of requirements. Therefore, research will need to be done how DUWO can implement a performance-based program of requirements that can be used for modular construction. This were three examples, but basically this will need to be done for every recommendation that was made in chapter 6.

Furthermore, as illustrated in the previous chapter about limitations, this research only focused on 3D modular construction, while 2D modular construction also has a lot of potential. While 3D modular construction achieves a faster building time on site and a better quality can be guaranteed, 2D modular construction loses no space due to double layers and more different shapes can be built. This shows that 2D modular construction solves some of the obstructions of 3D modular construction, but also reduces some of the advantages that 3D modular construction has. Because of the difference between 3D and 2D modular construction it would be helpful to do further research to the difference in advantages and obstructions between 2D and 3D modular construction. This way it is possible to make an informed decision between the use of 2D or 3D modular construction.

During the analysis of the measured KPI's not everything could be explained. For example, the high maintenance cost of the traditional building compared to the modular buildings could not be explained. An attempt was made to discover the reason, but it appeared to not be that easily explained. This is because many different parties are responsible for the maintenance of the building, which makes that it is very difficult to get to the root of this high cost. Based on the case study analysis it seemed that maintenance wise, modular construction performed a lot better than traditional construction, but this cannot be proven just yet. If modular construction would require significantly less maintenance, this would be very positive for modular construction and can be seen as an advantage of modular construction. Due to a lack of time, this was not further researched, but this lead should be investigated further.

9 REFLECTION

In this chapter I will reflect on the chosen research method for this graduation thesis and the process that was needed to go from P1 to P5.

9.1 METHOD

To do this research I first started with doing literature research. This literature research gave me a better understanding about modular construction, what is important, what has been researched and where the problems are related to the implementation of modular construction. Therefore, I think this was a good first step, which also was promoted by the university though the graduation process in which you first have to write a topic proposal, which stimulates you to first look at literature.

For me the graduation process was no straight road. From the beginning it was clear that I needed to define what modular construction is and what the obstructions and advantages of modular construction are, but for me it was hard to figure out how I could find solutions for increasing the uptake of modular construction. For me it was interesting to research how the uptake of modular construction could be increased, because according to literature modular construction had many advantages over traditional construction such as: reduced building cost, increased building speed and reusability. First, I thought it could be interesting to analyse to what extend modular buildings made by DUWO encountered the obstructions discovered in an earlier question, and to find solutions for these obstructions through interviews with experienced stakeholders. Finding these obstructions would however have been quite hard because most obstructions are no product obstructions, but mainly process obstructions. It seemed more interesting to take another route at providing research that could increase the uptake of modular construction, and therefore I changed my research question to involve a performance measurement. This meant that I could still analyse the modular buildings, but that I would use the method of performance measurement to do this. Instead of trying to overcome the obstructions of modular construction I could use the performance measurement to see on which aspects modular construction performed not that well and improve these aspects. It took me however until the P3 presentation to get a clear view of what exactly the end product would be of my graduation research. Until P3 I wanted to make an optimized standard module design for DUWO in which I incorporated the lessons learned from this performance measurement. However, the further I got in my research the more I realised that it was not a very good idea to make a standard module design for DUWO. There were a few reasons for this, the main one being that this standard design would reduce innovation of modular manufacturers and that DUWO would have to deviate from the standards that modular manufacturers already have. If DUWO deviates from these standards, DUWO will have to make their own production line to make it affordable and make a contract with one single manufacturer to make this possible. Furthermore, the design that I would have made would be incorporating elements such as TCO and extensive sustainability and I noticed that DUWO as an organisation is not ready for this yet. Therefore, I changed from design-oriented research to more process-oriented research in which I gave recommendations to DUWO that they can follow. By doing a step back and making this research a bit less specific, this research can be used not only by DUWO, but also by other housing associations with improving the performance of modular construction.

To execute this research an explorative research type has been used, because in this research the performance of modular construction will be explored together with possible solutions to increase this performance. To do this, the research method of case studies has been used, which expresses itself in the form of in dept interviews and project case studies.

For the interviews a qualitative research method was chosen, because not much literature was available about the performance of modular buildings and solutions for increasing the performance of modular multistorey student accommodations. Therefore, a quantitative research method would not have made sense, because for a quantitative research method it is necessary that already quite a bit of information about the topic is available on which the interview questions can be based. By doing qualitative interviews it was not necessary that a lot about the topic is already known, and therefore the questions change as more is learned about the topic. This learning process worked very well for my graduation research as this way follow up questions could be asked, and newly discovered topics could be incorporated in the next interviews. I started with a set number of questions and as I did more interviews I added and deleted questions that I thought were relevant and needed more explanation. When the interviews were done, I summarized what was said in the interview. This gave me another chance to clearly think about what the interviewee said, and it provided a reference which I could use in my research.
For the project case studies a qualitative research method was chosen as well. This was done, because all projects are different, and an in-depth insight was needed into the buildings to understand the performance of the buildings. I compared the buildings based on different KPI's and set parameters so that the buildings could be compared with each other, which seems like a quantitative approach. However, the buildings have been specifically introduced and, in the analysis, the specific building characteristics have been considered. Therefore, I would consider this research more qualitative than quantitative. This research method worked well, because it provided a relatively clear overview of what building aspects performed well and which aspects did not perform well. For these project case studies I had to do research to the satisfaction of students. This is important to consider, because DUWO builds for students and therefore the student satisfaction has to be considered when building modular buildings. I had the chance to make a survey in which I asked students about their satisfaction with their room and if they wanted to change anything about the room. In this survey I used open and closed questions to quickly compare the answers, but also to get an explanation of the results. This survey helped me to understand how satisfied students were with their room and how this satisfaction could be improved.

9.2 PROCESS

Road to P2

I started my graduation process at the beginning of the academic year 21-22 by thinking about a topic that was interesting to me and that presented a relevant societal problem. Because my brother was trying to buy a house and he experienced some difficulties due to the affordable housing shortage in the Netherlands, I started thinking about how I thought this problem could be solved. I first started looking at wooden prefab construction, but when I was watching some YouTube videos about the tesla factory and the automation they use to make the car building process more efficient, I thought why isn't this used for the building sector. So, I googled "huizen bouwen in de fabriek" and this way I got acquainted with the topic of modular construction, which was completely new to me. I started reading into modular construction and I wrote my first topic choice at the start of the graduation process about modular construction. When reading about the advantages that modular construction can offer, I thought why isn't modular construction used more often if it can provide cost reduction, environmental benefits and increased production compared to traditional construction? I also looked into the obstructions for modular construction, and they didn't seem impossible to overcome, so my first version of my research question focused on how the obstructions of modular construction could be overcome. I thought this research fitted well with the section of design and construction management (DCM), because the obstructions were mostly managerial problems and not technical. I also chose Peter de Jong as my graduation mentor because Peter has been active in the field of modular construction through student projects MOR and SUM.

To get more acquainted with modular construction Peter encouraged me to interview team SUM, but then the opportunity provided itself to join team SUM as a construction crew member, which I did. To be able to spend the most time at team SUM I dropped my 10 EC of electives to be able to follow the SUM elective, which made it possible to fully focus on SUM and gain knowledge about modular construction. I really enjoy physically working at a construction-site, as I did this before during my HBO bachelor and therefore it was a win win situation for me. To really get the maximum amount of information out of this opportunity, I joined the construction coordination team within SUM, which gave me insight in planning as well as executing the work.

During this period, I started looking at finding a company to do my graduation internship and I found Dev real estate through an event from the study association from MBE (BOSS). After a few meetings they thought the topic of modular construction didn't fit with their working style and therefore this internship didn't work out. Based on recommendations from my second mentor Herman vande Putte, I thought focussing my research specifically on student accommodations was interesting. This is because student housing faces the same problems as the housing market and student housing is ideal for modular construction, because the student rooms are the same size as a 3D module. Therefore, I contacted DUWO and they thought the topic of modular construction was interesting and they were also asking themselves why modular construction is not used more often. Furthermore, the reason for choosing dev and DUWO was out of a personal interest for the development branch, which is very interesting to me.

In the period leading to the P2 presentation I started enlarging my knowledge about modular construction by reading a lot of literature, doing interviews and by doing a factory tour at Jan Snel. During this period, I found that my first research question to find obstructions and advantages did not fit well with my research method. I wanted to analyse modular DUWO buildings to see what could have been done better to improve the efficiency and suitability of modular construction. When analysing the obstructions and advantages of modular construction, the focus will be mainly on modular construction, which makes that other objectives such as the environment, student satisfaction and financial health would have a less prominent role in my research. Therefore, I changed the research question to involve a performance measurement, which not only looks at modular construction, but also considers other important perspectives. This development gave me a lot more insight in modular construction and made that I was sufficiently prepared to pass my P2 presentation.

Road to p4

The main feedback on my P2 presentation was that the definition of performance should be defined and that that I should get a better understanding about if modular construction is really a good idea for the built environment. I started with defining the definition of performance, which I used to determine the aspects that should be looked at when examining the performance of modular buildings. When the definition of performance was clear to me, I started interviewing different employees within DUWO and I asked them about the objectives of DUWO and their expectations of modular construction. This gave me a lot of insight in how DUWO employees think about modular construction, and it was a great opportunity to get to know the DUWO employees. Initially I thought that based on these interviews I could determine performance elements with which I could determine KPI's that could be used to measure the performance of modular DUWO buildings. After I did the interviews, I realised that most interviewees said something around the lines of: realising as many affordable student housing as possible while taking into account the wellbeing and student satisfaction. I noticed that no one mentioned something about realising sustainable buildings, which has to be an important objective of DUWO considering the climate crisis. Because this objective missed in the interviews I started to wonder if more important objectives could be missing. When talking about this finding with a DUWO employee I was pointed at the policy paper of DUWO in which they defined the objectives of DUWO. This policy paper in combination with the interviews gave me a great indication of what is important for DUWO. However, if the performance of modular construction should be improved not only the perspective of DUWO is important to consider. Therefore, based on advice from Herman vande Putte I started zooming in from objectives from the entire built environment to the objectives specific for DUWO, which helped me with determining which objectives should be important for DUWO.

Once the important objectives were clear I determined different KPI's that could be used to measure the objectives in the DUWO buildings. Based on these KPI's I started gathering more detailed information about the buildings that I wanted to analyse. In the P2 period I had already started with gathering some general information about the buildings that I knew I would need anyways, such as drawings, details and building cost. This was however very difficult and halfway P3 I finally had the general information about the to be analysed buildings. The main reason that gathering this information was so difficult was because employees from DUWO did not know that well who I needed to approach for specific information and because sometimes it took a very long time before people replied. What also could have helped with gathering this information was if I had a better idea of what KPI's I exactly wanted to analyse more at the beginning, so that I could have sent this around among different DUWO employees.

I wanted to use this performance measurement to determine which building aspects perform bad and improve this performance by finding solutions for these bad performing building aspects through interviews. Because I did miss most important information with which I could do the performance measurement I could not start with this approach. Until this point, I thought that I would want to make a standard module design for DUWO, but I realised that DUWO was not ready for this big of a step yet. Therefore, I decided to just start writing about how DUWO should implement modular construction to save building cost. I started with building cost, because through interviews with DUWO I noticed that building cost is currently an issue for DUWO. I had already started interviewing different professional stakeholders and therefore I could already write about this topic.

The feedback that I got for my P3 presentation was that I was going in the right direction and that from now on every once in a while, I should zoom out and check if I was still following my research questions. After the presentation I continued writing recommendations for DUWO and I continued with gathering information about the buildings to use to measure the performance of these buildings. A few weeks after P3 I had gathered all information and I started to analyse the information and I measured the performance of the buildings. Based on this performance measurement I could continue to write recommendations for DUWO that they can use to improve the bad performing building elements. To write the recommendations interviews were planned about once every week. After every interview I added the insights gained from the interviews to the recommendations and added the new insights to the interview questions for the next interviewee to confirm or deny. This worked very well for me as this way the recommendations could be easily verified by at least two professional stakeholders. Furthermore, if new recommendations were found through the interviews, I also contacted the right person within DUWO to check the feasibility of the recommendation. This resulted in recommendations to increase the performance of modular construction that should be feasible to implement for DUWO.

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APPENDIX A: INFORMATION SHEET INTERVIEW

Onderzoek:	- A post occupancy evaluation informed design to increase the uptake of modular multi-storey student accommodations
Instituut:	- Delft University of Technology
Onderzoeker	- Kevin Vader – a.f.k.vader@student.tudelft.nl – +31 6 24700595

Met dit document wil ik u wat informatie geven over de deelname aan mijn onderzoek.

Onderzoek

Voor mijn afstudeerproject van de Master Management in the Built Environment aan de TU Delft ben ik samen met studentenhuisvester DUWO een onderzoek aan het doen naar het opschalen van het gebruik van modulair bouwen. Hierbij focus ik met name op studenten huisvesting en 3D modulair bouwen. Dit onderzoek analyseert de voordelen van modulair bouwen en de belemmerende factoren die het gebruik van modulair bouwen tegenhouden. Ook biedt het oplossingen om deze belemmerende factoren te verminderen door interviews af te nemen en literatuuronderzoek te doen. Het doel van dit onderzoek is om een gestandaardiseerd ontwerp te maken voor een modulaire studentenwoning, dat is gebaseerd op de resultaten van het gedane onderzoek.

In dit interview zullen de volgende onderwerpen aan bod komen:

1. Uw professionele achtergrond
2. Ervaring met modulair bouwen

Datagebruik voor het onderzoek

Het interview zal worden opgenomen, zodat later de audio opname teruggeluisterd kan worden en er een samenvatting van het interview kan worden gemaakt. Uw professionele achtergrond zal worden gedocumenteerd, maar uw persoonlijke informatie zal niet worden vermeld in de samenvatting van het interview.

Datagebruik na het onderzoek

Nadat het onderzoek is afgerond en ik mijn rapport heb ingeleverd zal mijn onderzoek online worden gepubliceerd op het onderzoeksplatform van de TU Delft (https://repository.tudelft.nl). Dit wordt gedaan om data beschikbaar te maken voor verdere kennisontwikkeling, onderzoek en innovatie. De hele samenvatting en audio opname zal echter niet worden gepubliceerd en zal uitsluitend binnen het onderzoeksteam blijven wat bestaat uit ikzelf (Kevin Vader), mentoren vanuit de TU Delft (Peter de Jong en Herman vande Putte).

Bij voorbaat dank voor de medewerking en bijdragen aan dit onderzoek!

Interviewvragen

//

De interviewvragen werden hier toegevoegd, zodat de geïnterviewde deze alvast door kon nemen en op de vragen kon voorbereiden voor het interview. De vragen waren voor elke geïnterviewde anders en zijn daarom hier niet toegevoegd.

//

APPENDIX B: INFORMATION SHEET INTERVIEWS

Algemene informatie

Datum:

Geïnterviewde:

Bedrijf:

Functie:

Interviewer: Kevin Vader

Introductie

Bedankt voor het deelnemen aan mijn onderzoek door het afnemen van dit interview. Voor mijn afstudeerproject van de Master Management in the Built Environment aan de TU Delft ben ik samen met studentenhuisvester DUWO een onderzoek aan het doen naar het opschalen van het gebruik van modulair bouwen. Hierbij focus ik met name op permanente studenten huisvesting en 3D modulair bouwen. Dit onderzoek analyseert de voordelen van modulair bouwen en de belemmerende factoren die het gebruik van modulair bouwen tegenhouden. Ook biedt het oplossingen om deze belemmerende factoren te verminderen door interviews af te nemen en literatuuronderzoek te doen. Het doel van dit onderzoek is om een gestandaardiseerd ontwerp te maken voor een modulaire studentenwoning, dat is gebaseerd op de resultaten van het gedane onderzoek.

Met dit interview wil ik meer inzicht krijgen in wat jullie hoofddoelen zijn als organisatie en welke aspecten binnen het bouwproces als na oplevering belangrijk zijn. Ook wil ik inzicht krijgen in hoe jullie modulair bouwen zien ten opzichte van traditioneel bouwen. Deze informatie wil ik gebruiken om de prestatie van de modulaire gebouwen te meten.

Datagebruik na het onderzoek

Nadat het onderzoek is afgerond en ik mijn rapport heb ingeleverd zal mijn onderzoek online worden gepubliceerd op het onderzoeksplatform van de TU Delft (https://repository.tudelft.nl). Dit wordt gedaan om data beschikbaar te maken voor verdere kennisontwikkeling, onderzoek en innovatie. De hele samenvatting en audio opname zal echter niet worden gepubliceerd en zal uitsluitend binnen het onderzoeksteam blijven wat bestaat uit ikzelf (Kevin Vader), mentoren vanuit de TU Delft (Peter de Jong en Herman vande Putte).

Interview vragen:

1. Professionele achtergrond
    - Wat is uw functie binnen de organisatie waar u werkt?
    - In welke mate komt u in aanraking met modulair bouwen tijdens uw werk?

2. Hoofddoelen

    Ik ga u wat vragen stellen over verschillende doelen van duwo uit het ondernemersplan van duwo. Bij het antwoorden van deze vragen moet u uitgaan van nieuwe gebouwen zowel modulair als traditioneel en als het gaat over modulaire gebouwen wordt er uitgegaan van een permanente functie.
    - Wat zijn volgens u de meest belangrijke doelen van duwo?
    - Een doel is om op een duurzame manier de gebouwvooraad uit te breiden en om het doel van co2 neutraliteit in 2050 te behalen. In welke mate denkt u dat dit doel nu al wordt behaald en wat moet er volgens u nog gebeuren? Is er een verschil tussen modulair en traditioneel?
    - Het aanbieden van een betaalbare woning is een hoofddoel van duwo (servicekosten meegenomen). In welke mate wordt dit doel behaald en wat kan er volgens u nog beter? Is er een verschil tussen modulair en traditioneel?

- Innovatief en efficiënt werken is een doel van duwo. Hoe is dit terug te zien in de gebouwen die jullie maken? Is er een verschil tussen modulair en traditioneel?

3. Verwachtingen modulair bouwen
    - Wat zijn uw verwachtingen van modulair bouwen? (Zowel positief als negatief)
    - Wat zijn uw verwachtingen van de modulaire bouwer?
    - Wat zijn voor u redenen om te kiezen voor modulair bouwen of traditioneel bouwen?
    - Is er volgens u een verschil in de eisen die gesteld worden tussen modulair bouwen en traditioneel bouwen? Bijvoorbeeld mag modulair bouwen meer/minder kosten, moet modulair bouwen duurzamer gedaan worden? Moeten modulaire gebouwen demontabel zijn? Levensduur?

APPENDIX C: TCO CALCULATION DUWO KITCHEN

TCO factsheet keuken nieuwbouw		Basis	Traditioneel gemiddeld			Magere K-A-A-S (KTK keuken)		
Keukenopstelling DUWO standaard 3x3 met verlengd blad en opstelplaats koelkast		initiële	Jaar		Totaal	Jaar		Totaal
		aanschafprijs						
			1-25	26-50		1-25	26-50	
1 Onderdelen mbt keuken								
Aanschaf rechte keuken		1.290,00	1.290,00	1.290,00	**2.580,00**	2.015,15	1.027,73	**3.042,88**
Wisseling kunststof blad		0,00	0,00	0,00	**0,00**	0,00	0,00	**0,00**
Montage		299,00	299,00	299,00	**598,00**	299,00	199,00	**498,00**
Transport		99,00	99,00	99,00	**198,00**	99,00	99,00	**198,00**
Dubbele wandcontactdoos	2	100,00	200,00	200,00	**400,00**	0,00	0,00	**0,00**
Tegelwerk nieuwbouw/renovatie		100,00	100,00	100,00	**200,00**	0,00	0,00	**0,00**
			1.988,00	1.988,00		2.413,15	1.325,73	
Aanschaf of lease apparaten Bosch		€/st.	2	2		2	2	
Inbouw inductie kookplaat	PIE645BB1E	0,00	0,00	0,00		0,00	0,00	
Wandschouwkap 60 cm	DWB67CM50	0,00	0,00	0,00		0,00	0,00	
Vlakscherm afzuigkap 60 cm	DFM064A52	0,00	0,00	0,00		0,00	0,00	
Plasmafilter	Purivent	0,00	0,00	0,00		0,00	0,00	
Inbouw koel-vriescombinatie 1772mm	KIV86NFF0	0,00	0,00	0,00		0,00	0,00	
Inbouwkoelkast met vriesvak 1025mm	KIL20NFF0	0,00	0,00	0,00		0,00	0,00	
Inbouwkoelkast met vriesvak 880mm	KIL18NFF1	0,00	0,00	0,00		0,00	0,00	
Oven 60 x 60 cm RVS	HBF114BS1	0,00	0,00	0,00		0,00	0,00	
Compacte magnetron met hetelucht 60 x 45 cm RVS	CMA583MS0	0,00	0,00	0,00		0,00	0,00	
vaatwasser 60 cm	SMVHU800E	0,00	0,00	0,00		0,00	0,00	
totaalbedrag apparaten		0,00	0,00	0,00	0,00	0,00	0,00	0,00
totaalprijs keuken incl. montage + apparaten		**1.888,00**	**1.988,00**	**1.988,00**	**3.976,00**	**2.413,15**	**1.325,73**	**3.738,88**
2. Servicekosten								
service keuken	20	42,00	**840,00**	**840,00**	**1.680,00**	**1.072,80**	**1.072,80**	**2.145,60**
service apparaten								
SOM (service op maat)								
aanname servicekosten (vervanging onderdelen incl arbeid)	5	0,00	0,00	0,00		0,00	0,00	
voorrijkosten per keer	5	0,00	0,00	0,00		0,00	0,00	
totaal service-en voorijkosten apparaten			**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**
3. Aanleg E-installatiepunten								
Install. werkzaamheden + voorbereiding		0,00	0,00	0,00		0,00	0,00	
Stekerbare doos + toebehoren		0,00	0,00	0,00		0,00	0,00	
Totaal installatiekosten			**0,00**	**0,00**	**0,00**	**0,00**	**0,00**	**0,00**
4. Aanleg W-installatiepunten								
Install. werkzaamheden + voorbereiding		165,00	**165,00**	**165,00**	**330,00**	**0,00**	**0,00**	**0,00**

5. Demontage en transport*								
Demontagekosten en transport nieuwbouw/renovatie		350,00	**350,00**	**350,00**	**700,00**	**0,00**	**0,00**	**0,00**
6. Terugkoopverklaring								
Restwaarde vergoeding			**0,00**	**0,00**	**0,00**	**0,00**	**-250,00**	**-250,00**
Totaal kosten			**3.343,00**	**3.343,00**	**6.686,00**	**3.485,95**	**2.148,53**	**5.634,48**
Verschil Traditioneel en Chainable								1.051,52

Toelichting onderdelen keuken	*werkzaamheden omtrent demontage en afvoer oude keuken + toebehoren wordt niet uitgevoerd door Chainable, deze kosten zijn geschat op basis van werkzaamheden die worden uitgevoerd door de onderaannemer
	Tegelwerk niet van toepassing bij keukens van Chainable vanwege gehard glazen achterwanden met levensduur 45 jaar
	Bouwplaatskosten vallen traditioneel hoger uit omdat de keuken 2 keer vervangen gaat worden (te verwachten besparing bij een Chainable keuken 300 euro)
	Inclusief 2 bomen planten per keuken
	Inclusief (modulair granieten) blad
	Inclusief gehard glazen achterwanden
	Inclusief preventief onderhoud
	minimaale overlast bij schilvervanging keuken
	service+garantie apparaten 20jaar geen vervangings- voorrijkosten