The influence of consumer choice on the process of industrialised housing construction

A Case Study at: CASCOTOTAAL

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Djon Oscar Snel

Student number: 4382072

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Graduation committee

Chairperson	: Prof.dr.ir. M.F.W.H.A. Janssen, TPM-ICT
First Supervisor	: Ir. M.W. Ludema, TPM-TLO
Second Supervisor	: Dr. H.J.F.M. Boumeester, OTB
External Supervisor	: Drs. L. de Kok, CascoTotaal

Executive summary

Traditional housing construction in The Netherlands has not changed significantly in the last centuries. New building materials were the main focus of innovation, while the traditional process of housing construction remained very inefficient with only 40 to 60 percent of the working hours being productive (Ahmed & Forbes, 2010; Aziz & Hafez, 2013). This results in a Dutch housing market that is currently facing a growing gap in demand and supply of houses. At the moment demand is 1,5% larger than supply and this is projected to grow to 2,6% by 2020 (Minister Wonen en Rijksdienst, 2016a). The solution lies in recent innovations in construction methods which made it possible to construct houses more efficiently and shorten the total construction time significantly by using prefabrication techniques (CascoTotaal B.V., 2016; MorgenWonen, n.d.; Think Wonen, n.d.).

During a literature review, it was found that traditionally (future) house owners have a negative view of prefabricated houses due to the impossibility of customisation to their preferences (Gann, 1996; Laing, Craig, & Edge, 2001). Currently, industrialised housing construction is mainly focussed on larger quantities of production for housing associations or developers with a great amount of standardisation in order to keep the price low. Incorporating standardisation into the process is most efficient for the industrialised housing construction company. But, in order to expand the market potential, customisation needs to be offered to satisfy the (future) consumer. However, introducing customisation means more variation in the process and a more challenging supply chain.

This master thesis discusses the trade-off needed between standardisation and customisation in order to satisfy the consumer preferences without losing the efficiency of industrialised housing construction. The goal of this research was to identify the influence of this trade-off on the supply chain and external effects by answering the following research question based on a conceptual design wherein the customisation trade-off is intervening in the industrialised housing construction supply chain and external performance:

"What it the influence of consumer based customisation on the supply chain and external effects in industrialised prefabricated housing construction at CascoTotaal?"

In order to answer the research question, a literature based case study has been designed and executed at CascoTotaal B.V. (Initiator of this research and a competitive player in the industrialised housing construction market). The case study consists three parts: Current situation analysis, Future scenario creation and Effects mapping.

During the current situation analysis, the supply chain and process were mapped using a SCOR model focused on the physical stream of goods and a BPMN model to map the information flow through the process and stakeholders involved. From these two mappings, the current Customer Order Decoupling Points (CODPs) were determined and following the model of (Barlow et al., 2003; Hoekstra & Romme, 1992) these CODPs were translated into five levels of customisation; ranging from Pure Standardisation to Pure Customisation.

In order to get a clear overview of the CODPs, the product under examination (the final house) has been split into seven modules (Structural work, Interior layout, Technical systems, Interior finish, Exterior finish, Kitchen and Bathroom) by combining the modularisation of (Hofman, Halman, & Ion, 2006) and (Schoenwitz, Gosling, Naim, & Potter, 2013).

The conclusion of the current situation analysis is, by examining the customisation levels of each module, that from the perspective of the customer the levels of customisation are relatively high with all modules categorised between Customised Standardisation and Pure Customisation. To close the current situation analysis, a preliminary external effects mapping has been performed to find the strong and weak points of CascoTotaal compared to traditional housing construction based on five external effects categories extracted from (Gann, 1996; Hsieh, 1997; Lu, 2007; Pan, Gibb, & Dainty, 2008): Construction time, Construction costs, Quality, Safety and Environment. Overall, the positive effects of industrialised housing construction outweigh the negative effects. Due to the limited amount of process data however, the effects could not be quantified. Except from this the external effects categories where extracted to be used later.

To create a possible future scenario for CascoTotaal the consumer preferences were incorporated into the process. In an earlier stage, it was found that the amount of customisation for the customer of CascoTotaal was not directly translated to the consumer (or user of the house). For this, the CODPs from the consumer perspective were mapped and it was concluded that all product modules offer fewer customisation possibilities to the consumer as for the customer. Most modules were being categorised as Pure Standardisation and some as Segmented or Customised Standardisation.
A limitation analysis was performed to explain the limitations of customisation and to determine both technical and logistical limitations for all seven product modules. The outcome of the logistical limitation for the final unit (structural work module finished in the finishing factory to be transported as separate sections of the final house) were the limits by maximum dimensions (height, width & length) and the maximum weight to be transported on public roads. However, no explanation was found for the limited customisation transfer between customer and consumer. Therefore, the consumer preferences as measured by (Hofman et al., 2006) were used to translate the expressed consumer preferences into COPDs for the process of CascoTotaal in order to find the most feasible positioning of the COPDs. By adopting the COPDs matrix of (Schoenwitz, Potter, Gosling, & Naim, 2017), these exact COPDs where transformed into a possible spread wherein the most feasible COPDs should be positioned depending on limitations, so that the final position could be moved without significantly impacting the consumer satisfaction. By now combining the creaded spread with the module specific limitations, the customisation trade-off could be made in order to determine the final most feasible CODPs positioning based on consumer preferences. The final most feasible positioning placed the Structural work, Interior layout, Technical systems and Exterior finish modules at the level of Customised Standardisation. The modules; Interior finish and Bathroom where categorised as Tailored Customisation and the Kitchen module was placed in between Tailored- and Pure Customisation.

In the final phase of the case study, the supply chain and the external effects of changing the CODPs positioning from the current level of customisation to the most feasible positioning were Determined. This was achieved by first performing a test for alignment between the current CODPs positioning from both the consumer and customer perspective and the most feasible positioning. It was seen that for all modules, the current process did not offer a sufficient level of customisation to the consumer and for the Interior finish module, even the customer level of customisation did not meet the most feasible positioning. During the gap analysis, the required process interventions needed to reach the most feasible level were further explored for each product module. Based on these interventions, the supply chain effects where determined with regards to the process impact and logistical impact.

The main impact on the process with the incorporation of consumer preferences is the shift in the information flow. Except for the Kitchen and Bathroom modules, all other modules experienced a shift in the point where the information flow meets the physical flow. The required information will be available at a later stage. Another finding is that there are multiple non-value adding stakeholders in the information flow. Information is just passed on from one stakeholder to the next, with a great risk of information inaccuracies or delays. It is concluded that optimisation is needed in the physical process to cope with the fluctuating demand when customisation is brought into the process. In order to optimise the efficiency of the process, steps need to connect to each other. This also minimise the negative effects of increased fluctuations in demand and (sub)components needed per module.

The impact on logistics in the process show that most product modules need to shift from an anticipatory logistical system to a reactive logistical system due to the increase in fluctuations in demand. This means that demand is no longer forecasted and ordered in advance, but ordered once it has been chosen by the consumer. This increase in fluctuating demand is caused by the need for more customisation features per product module in order to achieve the most feasible positioning. In order to add more customisation features, however, the relationship with the first-tier suppliers need to improve significantly into a long-term relationship. Like there is currently between CascoTotaal and Bouwcenter Logus De Hoop. More suppliers need to become co-makers in order to create a steady logistical system.

The current situation external effects analysis provided the categories for the external effects matrix. By mapping the external effects, a further analysis was made. This concluded that the most influential effect for CascoTotaal would be the increase in off-site construction time at the finishing factory caused by the addition of customisation features. Adding extra process steps decreases the amount of repetition and thereby the learning effect, increasing the time it takes to complete the separate tasks. The lack of repetition impacts the internal quality of the final product by causing more production mistakes. Finally, the introduction of customisation causes a significant external effect on the construction costs. Additional customisation features result in a larger range of pricing for the final product.
To calculate the effects on the market positioning, a market repositioning analysis has been performed using the housing valuation system of the Dutch Government (Huurcommissie, 2016). This research concluded that a standard Spero 1 single family house with customisation features was not suitable for the social rent housing market. Even the minimal configuration scored above the maximum allowed points for social housing. For the private rent sector, it is concluded that the new customisable Spero 1 single family house will fit in the government stimulated “mid- priced” private rent sector of 700 to 1000 (incl. energy compensation) euro per month. Four configurations were calculated: two energy neutral configurations and two non-energy neutral configurations. Both with a minimum and maximum amount of luxury. The benefits of the construction concepts of at CascoTotaal together with the ability for the consumer (user) to configure their house with their preferences results in an acceptable higher price (950 to 1100) in the market. As a resident, you can determine your own rental price with no significant consequences for the house owner (customer of CascoTotaal).

Preface

This master thesis is written as the final project in the master program Management of Technology at the TU Delft. The preparation towards this thesis began 1,5 years ago when I enrolled into the Management of Technology master program. As my last project, this thesis will (hopefully) grand me the title: "Master of Science in Management of Technology".

I started my master program at the TU Delft after graduating with an honours title from the Amsterdam University of Applied Sciences in the Aviation Studies program. During my student career in Amsterdam my interest was drawn towards the internal processes of companies and especially the efficiency trade-off between customers and internal processes. This was the reason for me to switch from a more engineering oriented program to the more business and management oriented master program Management of Technology at the TU Delft.

During the research at CascoTotaal and writing of this thesis I experienced that the last 1,5 years in the master program excellently prepared me to the task of researching a scientific problem in a business environment driven by new technologies.

I could not have completed the work without the full support of everyone connected to this research. Therefore, I would like to thank my supervisors of the TU Delft: Marcel Ludema and Harry Bouwmeester as my first and second supervisors and Marijn Janssen as chair. I would also like to thank Leon de Kok and Vilmar Pouwer for their full support and supervision at CascoTotaal and all the interviewees who gave their input during the interview rounds of this thesis.

Lastly, I would like to thank my parents and girlfriend for their patience and cooperation during the different stages of my project.

Djon Snel,
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PART A – Research development

1 Introduction

Traditional housing construction requires all the needed resources (equipment, building materials, personnel, etc.) to be brought to the construction site were the house is being constructed. Besides this, most of the construction is performed outdoors where it is impacted by for example weather influences. All this comes to the result that the traditional way of the housing construction process is time-consuming and inefficient. The result of this inefficient way of construction is that just 40% to 60% of the time spend in housing construction can be calculated as productive as seen in a UK study (Ahmed & Forbes, 2010)(Aziz & Hafez, 2013). Another study found that this reduced productivity can be accounted to ten main factors (Jarkas, Kadri, & Younes, 2012): Skill of labour, Material shortage, Labour supervision, Experienced labour shortage, Site manager and labour force communication issues, Lack of construction managers (Leadership), Weather influences, "Request For Information" delays, Labour transportation issues, Proportion of work subcontracted.

To maximise productivity and minimise the "waste" of traditional housing construction, Japanese housing manufacturers have used industrial optimisation techniques developed in the automotive industry in the past. These techniques were later described as lean manufacturing by (Womack, Jones, & Roos, 1990). In this process, the Japanese developed completely finished prefabricated housing panels to construct houses more efficiently on a larger scale. The panels were prefabricated in a factory and put together on the construction site to form a house (Gann, 1996). In The Netherlands, John Habraken published a book in 1961 where he predicted the end of mass housing construction due to the fact that house owners wanted more flexibility (Habraken, 1962). In his book Habraken explained the concept of "infill" (non-load bearing elements) and "support" (load bearing elements) construction. Especially in the support part of the housing construction multiple companies in The Netherlands innovated with prefabricated concrete parts that were made off-site in a factory and transported to the construction site in order create the structural part of the house fast and efficient while the infill could be tailored to the consumers' preferences. These industrialised ways of housing construction as seen in multiple countries takes away some of the earlier mentioned ten restrictions of housing construction. However, most of the construction still takes place on-site and requires a lot of material and sub-assembly transportation to and from the construction site. Also, most of the labour-intensive work is still performed on the construction site itself.

In the Netherlands the demand for housing is currently 1,5% larger than the supply of houses, it is even projected that this gap will further grow to 2,6% by 2020 (Minister Wonen en Rijksdienst, 2016b). To overcome this increasing gap in housing supply the construction rate of new houses in The Netherlands needs to be increased. With the traditional inefficient way of housing construction, this will require more investments in the housing construction sector. Another way of closing the gap in demand and supply is by producing houses more efficiently like the Japanese prefabricated construction system. However, from earlier research in the UK, it can be seen that house owners historically have a negative view on prefabricated houses due to the inability to translate their preferences into the standardized way of production (Laing et al., 2001). To overcome this negative view of prefabricated houses, an optimal level between the level standardisation in housing production and flexibility of customising the house by the future owner has to be found (Gann, 1996).

By combining the need for more efficient housing construction in The Netherlands and the known inefficiencies of current housing construction methods with improved industrialisation technologies gives opportunities for new innovations in housing construction. One of these new innovations is that houses can now be fully constructed indoors in an industrial way by using modular sections (Stedenbouw, 2016). This way of prefabricated housing construction is a next generation of industrial housing construction seen before. If it is compared to the "support" and "infill" method described earlier not only is the support now created industrially, also the infill in produced in a factory and not on the building site. The modules are fully assembled housing sections that are transported to the final destination by truck and connected together in order to create a complete liveable house in 8 to 10 days' time (CascoTotaal B.V., 2016).

2 Research approach

In this chapter, an overview of the research as performed for this master thesis is given. Starting with the research problem. The research problem is derived from a preliminary literature review which is further worked out into a full literature review later in this report. The researched problem for this thesis has two components, a scientific component adding to the knowledge of the scientific community and a societal component reflecting the new scientific knowledge to a societal situation. From the research problem, the objective is derived in the form of a conceptual framework. The conceptual framework is a result of the literature review as described later in this report. From the research objective, research questions are created to be answered. In order to answer the research questions and to solve the proposed research problem, a research method is designed.

2.1 Research problem

At the moment, industrialised housing construction is mainly focussed on the production of houses for housing associations on a large scale with lots of standardisation. As seen in the literature and in other industries, standardization is most efficient for the housing producers. However, the future customers or consumers require a certain degree of customizability in order to take away the negative view against prefabricated housing construction. So, in order to make these standard products appealing for a large customer base in the housing sector the industrialised housing construction sector needs to build in a certain level of customizability into their standardised products. However, customisation means more variation in the production process and a more challenging supply chain. Not only does the offering of customisation impact the internal processes and supply chain. It also impacts the external effects that are directly impacting the final consumer or outside world. So, in order to optimize the process of prefabricated housing construction there should be a balance between the level of standardization and customisation offered in the final product. However, this trade-off between customisation and standardization in housing construction is a very complex problem with multiple inputs and outputs. The level of customisation offered in the final product needs to be adapted to the level of consumer preference. The trade-off between standardization and customisation will have various effects on the internal operations of the construction company as well as on the external effects in the outside of the company. This research will address these various effects that are influenced by consumer preference integration in the process of industrialised housing construction inside and outside of the construction company.

2.1.1 Scientific contribution

This research will contribute to the scientific community by combining the work of different studies and testing the outcome of these it in a real-world situation using a case study at an industrialised housing construction company based in The Netherlands. It is seen previously that there are new more customer tailored ways of efficiently producing prefabricated houses on an industrial scale, but besides the practical problem of organizing the supply chain around this production process. The view of the consumer (future house owner) towards prefabricated houses needs to change. Research found that currently consumers have a negative view towards prefabricated houses due to the lack of customizability (Gann, 1996; Laing et al., 2001). How to integrate customizability and standardization in to one supply chain based on customer order decoupling points (CODPs) (That point in a supply chain where the product is linked to the order and/or preferences of the customer or consumer) is well described, but in housing manufacturing these theories have not yet been applied. It is unclear where these points are and what the influence of consumer choice is on these points. This research will test the theory of aligning consumer preferences with the process based on CODPs in a case study. Besides the implications on the supply chain, the literature discusses various external effects to the general public that are in place when houses are built in an industrialised way. However, the impact that incorporating consumer choice in this process could have on the external effects has not yet been researched. This research will therefore contribute to the knowledge on external effects in industrialised housing construction. The strategy of the prefabricated modular housing construction company needs to be aligned with the needs of the consumer by finding a trade-off and balancing the amount of customizability and efficiency in the same process and the effects on the external effects should be researched.

2.1.2 Contribution to society

The principle of lean manufacturing has been developed since 1990 in the car manufacturing industry. However this method of production has not yet fully penetrated the housing construction sector (Aziz & Hafez, 2013). Sub companies that produce building materials are more and more developing their processes according to the principles of lean manufacturing, but this lean process mostly stops as soon as the materials are transported to the building site where there are multiple factors introducing inefficiencies in the construction process (Ahmed & Forbes, 2010; Jarkas et al., 2012). Development of new technologies has made it possible for houses to be constructed in modular sections under controlled circumstances in an industrial manufacturing facility. But to realize this industrialised housing construction process the traditional supply chain for construction materials needs to be changed. This change will be very complex since it involves multiple stakeholders that have to coordinate their actions to be most efficient and align their processes with the preferences of the consumers. For this the preferences of the consumers' needs to be clear to the housing manufacturer, and the required needs for the subcontractors need to be known in advance.
By optimizing the supply chain for prefabricated housing and making the supply chain more consumer orientated, the historically encountered negative view of the consumer towards prefabricated housing should be improved. Also by aligning the supply chain on the consumer

side the supply chain on the supplier's side can be better optimized. Besides the supply chain, the external effects will be impacted when consumer choice is incorporated in the product. Therefore, a better understanding of the exact effects is needed to make a thoughtful balance between customisation and standardization in industrialised housing construction in The Netherlands.

2.2 Research Objective

The goal of this research is to find the influence that the offering of consumer based customisation has on the supply chain and external effects in industrial housing construction. A conceptual framework (Figure 1) is used to further examine the relationship between industrial housing construction, the supply chain of the modular prefabricated housing construction companies and external effects to the general public with the offering of consumer based customisation.

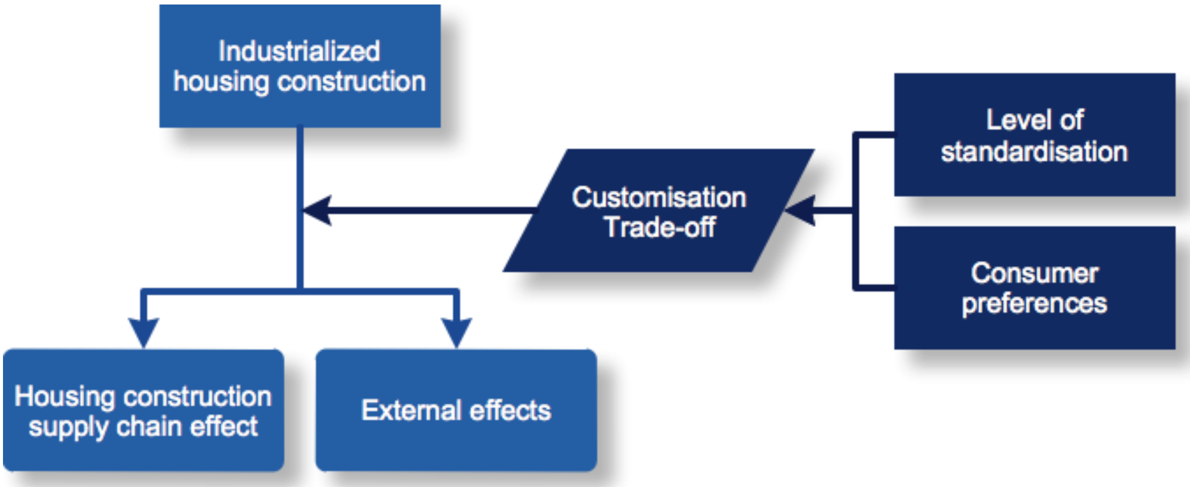

Figure 1: Conceptual framework

The framework consists of two parts; in the first part (light blue) the industrialised housing construction is the input. The method of industrialised housing construction and the product it makes influences the supply chain of the house constructed and the impact on the external effects. The second part (dark blue) of the framework takes consumer preference as seen required by the consumers and the level of standardization as preferred by the housing construction company as the input. Through the customisation trade-off in the final product the first part of the conceptual model is influenced. It is argued that when more customisation is offered the supply chain of industrialised housing construction will become more difficult and the impact on external effects will increase.

2.3 Research questions

Main question

Based on the previously stated problem statement and research objective the main research question will be formulated as:

Q1: What it the influence of consumer based customisation on the supply chain and external effects in industrialised prefabricated housing construction at CascoTotaal?

Sub-questions
In order to answer this main question multiple sub-questions are formulated:

SQ1: *What is the current flow of materials and information and who are the stakeholders in the supply chain of industrial housing construction?*

In order to research the impact of consumer based customisation on the supply chain, the current supply chain of industrial housing construction and its stakeholders first needs to be mapped. That is what this first sub-question will be used for. By answering this question, a base situation for the rest of the supply chain related research is set.

SQ2: *What are the positions of the customer order decoupling points in the current supply chain of industrialised housing construction?*

This sub-question is also used as a comparison situation for the rest of the research. In order to examine the influence of consumer preference, the Customer Order Decoupling Points (CODPs) in the supply chain will be used as the main focus point of the change. A model with all the CODPs in the current supply chain will be the outcome of this sub-question. Besides this model, the main attributes that determine the placement of the current CODPs will also be incorporated in this model. With this model, a future situation can be easily compared to find the impact of consumer based customisation on placement of the CODPs and on the attributes that will change the performance of the supply chain.

SQ3: *What are the most influential performance indicators of the industrialised housing construction supply chain?*

In order to get a full review of the current supply chain the most influential performance indicators of the supply chain need to be determined. These performance indicators are defined in this third sub question in order to finalize the supply chain of the base situation. Using the performance indicators, the exact influence of consumer preferences on the supply chain can later be determined.

SQ4: *What are the most influential external effects of industrialised housing construction?*

Besides the direct company effects that are described in the supply chain there are also effects of the new way of housing construction that do not directly affect the company itself. These effects are described in the literature in a general way about off-site or prefabricated housing construction. But the exact effects that are influenced by the way of construction is different per construction company and technique. Therefore, the exact influenced external effects that apply to the production technique of CascoTotaal need to be determined.

SQ5: *What are the most feasible Customer Order Decoupling Points in the supply chain model based on consumer preferences in The Netherlands?*

In order to be able to compare the current supply chain model of sub question 2 a most feasible CODP model needs to be created. The feasible model needs to be constructed based on the consumer preferences. This sub- question will be used to build this most feasible model of CODPs in the supply chain based on consumer preference found in the literature. A comparison with the current positions of CODPs will also be made in order to find the influence consumer preferences have on the supply chain. A comparison model will be the result of this sub question where multiple preferences can be used as an input and the difference in CODPs will be the output in order to find the most preferable trade-off between consumer preferences and the supply chain effects.

SQ6: *What is the influence of the most feasible CODPs on the performance indicators?*

In order to find the influence of consumer preferences on the supply chain, the most feasible CODPs were determined in sub question 5. However, the exact effects the consumer preference have on the supply chain will be measured using the performance attributes of sub question 3. The influence on the supply chain will be measured by comparing the shift in CODPs and their effect on the performance attributes.

SQ7: *What is the influence of the most feasible CODPs on the external effects?*

In sub question 4 the external effects that apply to CascoTotaal were determined. In this seventh and last sub question the external effects before the CODPs shift of sub question 4 are compared to the external effects after the shift in CODPs. By comparing these two situations the influence of consumer choice for the external effects can be determined.

2.4 Research Method

In order to achieve the previously stated research objective and to answer the main- and sub-questions, multiple research methods will be used. The research will consist of a literature study and a case study. A short description of why these two methods are chosen is given below.

2.4.1 Literature study

The main goal of the literature study is to get a clear overview of published work on the sections of this research as presented in the conceptual framework; industrialised housing construction effects on the internal building supply chain and external effects to the surrounding society, and the implementation of consumer preferences in to the industrialised housing construction process. The literature review on these two sections will form the starting point of the Theory testing case study (Dul & Hak, 2008, Chapter 4, 5, 6 and 7). Therefore, the literature study will have a contribution to all the sub questions in the form of a theoretical basis needed for the answering of the sub questions by using the case study.

2.4.2 Case study

In order to be able to test the theories found in the literature study a comparison situation in the real world is needed. In order to translate the theories from the literature in to a high quality testable situation a case study protocol is used following the method as described by (Stake, 1995; Yin, 2003). This case study protocol will be based on multiple theories as found in the literature and by combining these theories form a case study shell to be filled in by a case study research. The real-world comparison and the actual case study research will be done using a case study at an industrial housing construction company. The industrial housing construction company used for this case study research will be CascoTotaal, an industrialised housing construction company based in Zeeland, The Netherlands. CascoTotaal is selected for this research since the research is commissioned by CascoTotaal. The case is suitable since CascoTotaal is a serious player in the industrialised prefabricated off-site manufactured housing sector. By using CascoTotaal for the case study the results will very likely contribute to the knowledge building of consumer preference influence and its impact on the supply chain and external effects in the industrialised housing construction sector and its suppliers (Dul & Hak, 2008).

3 Literature review on the industrial housing construction process

The literature review of this research is split up into multiple parts based on the conceptual model as presented before. In the first section, the industrialised housing construction methods are analysed in order to research the link between industrialised housing construction and the housing construction supply chain. A literature review on current methods of industrialised housing construction is required to find the difference between industrialised housing construction and traditional housing construction methods. The literature review will therefore begin with a primary literature review on industrialised housing construction where several competing industrialised housing construction methods will be identified.

The second section of the literature review will concentrate around consumer preferences in housing construction and ways to incorporate consumer preferences in industrial processes. For consumer preferences of housing construction in The Netherlands (Hofman et al., 2006) will be used as a base situation. Hofman researched the preferences of (potential) house owners towards the opportunity to specify subsystems and components in a new house with a vignette-based survey. These preferences will be compared to other studies on incorporating consumer preferences in housing design. Besides the measurement of consumer preference also the incorporation of consumer preferences in housing design will be discussed in this section of the literature study.

The last section of the literature study will focus on the integration of the literature theories in the real-world situation by discussing methods of process and external effects analysis. Since the outcome of the literature review will be used in a theory testing case study, the literature review for external effects mainly focuses on primary literature dedicated to the change in building method from traditional to industrialised or off-site construction.

3.1 Industrialised housing construction

Innovation in the UK housing construction industry is hard and slow. This can be partly explained because firms active in the sector did not have to innovate (incrementally) to survive over time (Barlow, 1999). Firms that have innovated did not do this according to a thought-out strategy but innovated just to cope with short-term needs of the customers. It was also found that future house owners or tenants were not connected to the housing suppliers. This in sharp contrast to other industries where innovation has changed the way of processing completely, an example of this can be found in the automotive industry (Gann, 1996). Here customers have played a key role in the innovation of the product. It can therefore be thought that the involvement of (future) house owners is key to developing an industrial way of construction and there is a need for more involvement of the (future) house owner in the construction process.

A way of involving the (future) house owner in the construction process could be by linking the principle of Lean manufacturing to the principle of Open Building (Cuperus, 2003). Open

Building focuses on the people who live in the house and the environment they like to live in. It strives to create a situation where people take *"responsibility for their own territory"* (Cuperus, 2003, p. 2). Open Building can be connected to Lean manufacturing because both principles involve the elimination of "waste" during the production process.
Open Building cuts this waste by coordinating dimensions and position of separate subsections of the house with the consumer beforehand in the design stage of construction. While Lean manufacturing cuts waste at the production site, therefore Open Building and Lean manufacturing can complement each other in separate stages of the construction process. However, in order to implement the principle of Open Building on an industrial process, where there is still some form of standardisation, the level of consumer influence needs to be determined.
Before this can be done a categorisation of industrialised housing construction is needed since there are different techniques of industrialised housing construction with accompanying levels of off-site fabrication. Looking at a way of producing houses one of the few who classifies housing construction based on the whole product, the house, instead of sub-components is provided by (Alistair G. F. Gibb, 2001). The product of a house is classified in to four production systems with varying degrees of off-site production. These four categories are further developed in (A.G.F Gibb & Isack, 2003). The four categories of housing construction are:

Component manufacture and sub-assembly
This method of housing construction can be compared to the traditional way of construction in The Netherlands. Raw materials and small sub assembled products are used to construct a house on-site.

Non-volumetric pre-assembly
In this production method two dimensional panels are constructed and finished off-site. Then the panels are transported to the building site and connected to form a house structure. The interior of the house is then finished on-site. In the Netherlands, multiple companies offer houses that are build using this production technique. Each company has its own level of off-site finish. As an example, multiple concrete suppliers in the Netherlands also offer unfinished prefabricated concrete panels. However, an example of a high degree of off-site finishing can be found in the concept of MorgenWonen by VolkerWessels (MorgenWonen, n.d.). in the MorgenWonen concept the outer walls of the structure are fully finished two dimensional panels that are connected on the construction site. The rest of the house is then finished on the construction site like the traditional housing construction method.

Volumetric pre-assembly
In volumetric pre-assembly, the items are also assembled or produced in a factory off-site. However, the difference with non-volumetric is that the products produced in volumetric enclose a usable space. The units produced are produced off-site and installed on-site within an independent support structure. In The Netherlands, the volumetric pre-assembly construction method is used for the construction of bathrooms and kitchens. Examples of this are for example found at Logus Prefab (Logus Prefab, n.d.) and HPB (HPB, n.d.). in these two pre-fabricated bathroom concepts the bathrooms are constructed off-site in a separate factory and transported to the construction site where it is placed in a structural shell. The bathroom unit is fully equipped and ready to be used once the utilities are connected.

Modular building
The fourth and final unit of classification is the modular building. The modular building can be compared to the volumetric pre-assemble, however modular building consists of both the support and infill. Modula building is the categorisation with the most work being performed off-site. The only work performed on-site is the connection of the modules and finishing operations. In The Netherlands innovations have been made in the modular building with examples seen at CascoTotaal (CascoTotaal B.V., 2016) and Think Buildingsystem (Think Wonen, n.d.) who build prefabricated fully off-site assembled concrete based housing modules that are connected on site to form a compete house. Another example is the Finch Buildings (Finch Buildings B.V., n.d.) that also constructs fully off-site assembled houses on a wooden basis.

With the classification based on these four categories it can be seen that there are different levels of industrialised construction besides the traditional way of housing construction. All the categories have a different level of off-site fabrication and therefore the influence of the consumer shifts from the construction site to the factory accordingly. However, in order to incorporate the preferences of consumers with regards to choosing options, the preferences of these consumers need to be made clear.

3.2 Consumer preferences in housing

In The Netherlands, a vignette-based survey was used to explore the consumer requirements of (future) house owners with regards to customisation in order to find what consumers require to be customised in a future house (Hofman et al., 2006). The research explored the relative importance the (future) house owner expresses against 34 housing components. Based on an explorative factor analysis it can be concluded that (future) house owners categorise customisation into five different levels: Floor plan, Interior finish, Exterior finish, Technical systems, Inner doorways. Based on these five levels, housing suppliers can develop packages to offer variation to the (future) house owner. These packages can maximise value to the consumer and minimise the costs and/or price. To offer this variety, building companies should be able to *"modularize their product portfolio"* (Hofman et al., 2006, p. 362). According to the researchers, it is therefore suggested that further research should be performed on: "*successful methods to define and implement modularization concepts in the building industry and investigate also its implications for the building supply chain"* (Hofman et al., 2006, p.362). So, with this research the categories of customisation are identified, but how the previously described degrees of consumer influence are not yet defined in The Netherlands.

In Germany, a different set of consumer requirements was identified based on Conjoint Analysis via an online survey (Schoenwitz et al., 2013). From this research seven categories of customisation were identified, ranked from most important to least important according to the (future) house owner these are: Construction Design, Heating, Home Technology, Sanitary Equipment, Facade, Internal Design and Additional Services (Garage, carport, landscape, etc.). By combining both lists (Table 1) of customisation preferences is can be seen that there is some similarity in the two, like *Technical systems* and *Home technology*. Also, *Floor plan* and *Internal design* can be seen as similar preferences like *Exterior finish* and *Façade*. However, there are also differences between the two sets of preferences. The difference with the biggest impact is that the preferences of (Schoenwitz et al., 2013) are ranked from most preferred to least preferred, and (Hofman et al., 2006) does not make any distinction in the preferences.

Table 1: Customisation preferences comparison

(Hofman et al., 2006)	**(Schoenwitz et al., 2013)**
Floor plan	Construction Design
Interior finish	Heating
Exterior finish	Home Technology
Technical systems	Sanitary Equipment
Inner doorways	Façade
	Internal Design
	Additional Services (Garage, carport, etc.)

It can therefore be disputed if the German preferences (Schoenwitz et al., 2013) and the Dutch preferences (Hofman et al., 2006) in housing construction are comparable?

3.3 Consumer based customisation in housing design

When defining customisation in an industrial processes five degrees can be identified: Pure standardisation, Segmented Standardisation, Customized Standardization, Tailored customisation and Pure customisation (Barlow et al., 2003). These five degrees are ranked from no consumer influence at all to totally made to consumer preferences. The three middle degrees of consumer influence can also be identified as mass-customisation, where the consumer has various degrees of influence but the producer still experiences economies of scale on the process. These three degrees of mass-customisation can be accompanied by basic supply chain models based on the customer order decoupling point (point in the process where the order and customer or consumer are linked together), however "*Mass customisation will not resolve basic issues such as construction quality or delivery time, both of which have to be acceptable to the customer before more customisation choices are offered"* (Barlow et al., 2003, p. 143). Therefore, other optimisation methods need to be combined with mass customisation to optimise the efficiency of the process. Also, the areas for mass customisation in housing manufacturing need to be defined in order to find the specific customer order decoupling points.

In The Netherlands, the research on the impact of consumer preferences on the housing suppliers supply chain was expanded by analysing the needed buyer-supplier relationships to offer custom features in prefabricated houses on a large scale (Hofman, Voordijk, & Halman, 2009). In order to find an answer to this relationship problem the following question was asked: *"what types of contractor–supplier relationships are needed to develop and produce a modular housing system successfully?"* (Hofman et al., 2009, p. 1). The research found that with the introduction of modules in housing construction, the level of integration between the models determines mostly determines the level of the relationship between the housing supplier and its supplier. The main point of the research was that the more modular a construction process becomes the more intense the buyer-supplier relationship will become and interdependencies of knowledge and investments are needed. However, the research concluded that *"Further research is needed to test the significance of the found relationships and the costs and risks of different contractor– supplier relationships"* (Hofman et al., 2009, p. 41). From this conclusion, it can be derived that there is no knowledge about the level of modularization required in the housing construction industry and the accompanying significance of the buyer-supplier relationship. This can be traced back to the consumer preferences because there is no distinction in the level of consumer preference, the level of modularization cannot be determined.

The same phenomenon of unknown level of customisation can be seen in the United States of America (US) where (Nahmens & Bindroo, 2011) continued the work of (Barlow et al., 2003) and (Hofman et al., 2006) by conducting an industry survey within the US housing construction industry. From the survey, it could be concluded that 40% of the US housing construction companies offer small changes to their standard product. These small changes can be compared to the tailored customisation as proposed by (Barlow et al., 2003). However, due to the unknown factor of consumer preferences, these customisations are not structured and the research concluded that the industrial housing production in the US has not yet achieved full mass customisation because of this. Therefore, the offers of customisation features in the US housing industry is far from efficient for the housing supplier.

Because the customisation features in Germany were better known, the housing supply industry could develop a better model for customisation features from the consumer preferences. (Schoenwitz, Potter, Gosling, & Naim, 2017) continued on the research of mass customisation in Germany and the impact on the supply chain by researching the customer order decoupling point (CODP) in the industrial housing construction sector in a case study. The research linked the earlier mentioned theory of consumer requirements (Schoenwitz et al., 2013) to the customer order decoupling point based on the five degrees of consumer influence (Barlow et al., 2003). This could be done because the consumer preferences were better known from previous research. The research concludes that it is possible to align the supply chain of prefabricated housing with the influence of the consumer on different levels, but to achieve these consumer preferences are needed (and are subjected to change) for the specific market. Recommendations from the researchers include the following: *"Even though an in- depth understanding of a single case study coupled with the survey responses can aid generalisation, further research, utilising additional cases and a wider survey are required to cover other populations and confirm the above findings"* (Schoenwitz et al., 2017, p. 89).
From this, it can be concluded that it is possible to align the supply chain of industrialised housing construction with consumer preferences. However, in order to achieve this, detailed information about the consumer preferences is needed. This information was available for the German market, but for the Dutch market this information is missing, and therefore the alignment of the supply chain with consumer preferences is nearly impossible.

3.4 Supply chain mapping

In order to determine the influence of consumer based customisation on the product and processes, these processes will need to be mapped. Process and supply chain mapping are well documented in the literature and can help firms to make their functioning visible, understandable and communicable. A well set up supply chain map can also help in the redesign of the current supply chain or provide a basis for the supply chain analysis (Gardner & Cooper, 2003). However, the kind of mapping technique to choose has to be done right in order to get the desired results from the mapping. (Gardner & Cooper, 2003) defined three main distinctions in the mapping of a process: Orientation, Level of detail and Purpose. With these three distinctions, a choice can be made between Supply Chain Mapping and Process Mapping.

Table 2: Supply chain mapping and process mapping (Gardner & Cooper, 2003, p. 45)

	Supply Chain Mapping	**Process Mapping**
Orientation	External	Internal (typically)
Level of detail	Low to moderate	High
Purpose	Strategic	Tactical

To generate the most detailed map of a company the two different mapping strategies can be combined. Supply chain mapping will be used to map the external processes, the linkages with suppliers and the suppliers of the suppliers and the links between the company and its customers on different levels. The supply chain takes a general perspective on how processes work between companies. The process mapping will generate a higher detail map of the operation within the company itself.

Two methods that are very well documented in the literature to construct these maps are Supply Chain Operations Reference (SCOR) model for the supply chain mapping and Business Process Model and Notation (BPMN) for the Process mapping.

SCOR

The Supply Chain Operations Reference (SCOR) model is a method of mapping a supply chain. The model was developed by companies joint together in the Supply Chain Council (Stewart, 1997). The SCOR model analyses the supply chain based on four levels: Plan, Source, Make and Deliver. In the later developed and now used SCORE model there is a fifth level, Return. The SCOR model is especially useful if the current performance needs to be compared to the required performance of the supply chain, or to set high level company targets.

BPMN

Business Process Model and Notation is an industry accepted way of mapping the internal business processes of a company (Dijkman, Hofstetter, & Koehler, 2011). BPMN uses a business process diagram to graphically depict the functioning of processes within a company. BPMN strives to provide a readily understandable picture of the business its processes to all the stakeholders. BPMN also consists of a standardized underlying business process execution language to optimize information systems within the business.

3.5 External effects of prefabricated housing construction

A second objective of this research is to find the impact not only on the internal processes of the company (those processes directly effecting the end product), but it also focuses on the external effects of the production process. These external effects do not directly have an effect on the company in a way the supply chain does, but it does effect the surrounding activities and people. The eco-management and audit scheme (EMAS) (European Union, 2013) provide a standardized list of environmental factor of the construction industry that are of importance to the European Union. However, the external factors of housing construction go further than the environmental impact. The external effects of prefabricated housing construction have been researched and documented very well in the literature. In the academic literature multiple advantages keep returning for modular prefabricated housing construction (Gann, 1996; Hsieh, 1997; Lu, 2007; Pan et al., 2008):

1) Reduction in construction time. Not only the total construction time, but especially the on-site construction time due to less disruptions and weather influences on the construction process.

2) Reduction in cost due to more effective planning, and more productive labour hours.

3) Improvements in quality is accounted to standardization of products and closer supervision during the process.

4) Reduction in safety risk during the construction work due to less weather influences, less work on heights and hazardous operations taking place at the same time.

5) Less environmental impact. Especially the modular factory constructed sections can be optimized to reduce production waste, soil- and water pollution and noise pollution on the construction site.

However, the exact amount of the effect depends heavily on the production process chosen by the housing construction company. Besides these positive external effects of prefabricated housing construction there are also negative effects. However, these negative effects receive far less attention in the literature. (Lu, 2007) describes four negative external effects of prefabricated modular housing construction. Mainly: the increased dependency on pre-project planning, the transportation of larger and heavier sub-assemblies over road, the negative perception of the general public towards prefabricated housing and the inflexibility of prefabricated housing towards last minute changes.

4 Case study design

In the literature study, multiple resources were found on industrial housing construction, consumer preferences in housing and the effects of industrial housing construction. Also, multiple methods of mapping a supply chain were discussed. In order to translate these theories, found in the literature study to a real-world application multiple options are available as described by (Yin, 2009).

A case study is chosen as the method to translate literature studies to a real-world scenario since it is able to test theories without interventions of the researcher in the tested situation while events happen simultaneous in time.

"The case study method allows investigators to retain the holistic and meaningful characteristics of real-life event" (Yin, 2009, p. 4).

"A case study is a study in which (a) one case (single case study) or a small number of cases (comparative case study) in their real life context are selected, and (b) scores obtained from these cases are analysed in a qualitative manner" (Dul & Hak, 2008, p. 4).

According to (Stake, 1995) an instrumental case study starts with the research question or research problem and seeks out a case that offers illumination. The case does not have to be typical but should maximise what can be learned about the phenomenon to be researched.

In order to perform a qualitative case study in a controlled way a case study design is needed in order to maximise the quality of the case study. This can be achieved through four critical conditions that are related to the design quality: construct validity, internal validity, external validity and reliability (Yin, 2003). In Table 3 the tactics that can be used according to (Yin, 2009) are given to ensure the maximisation of the case study quality per critical condition.

Table 3: Case Study Tactics for Critical conditions of quality (Yin, 2009, p. 41)

Critical conditions of quality	Case Study Tactic
Construct validity	- Use multiple sources of evidence - Establish chain of evidence - Have key informants review draft case study report
Internal validity	- Do pattern matching - Do explanation building - Address rival explanations - Use logic models
External validity	- Use theory in single-case studies - Use replication logic in multiple-case studies
Reliability	- Use case study protocol - Develop case study database

In the construction of this case study design, these critical conditions of quality and the accompanying case study tactics will be used to ensure maximum quality possible for this case study. In order to be able to translate the theoretical literature to a real-world situation the unit of analysis for this translation needs to be made clear.

4.1 Unit of analysis

This unit of analysis is also referenced to as the “case”. Therefore, in order to perform a case study, the “case” or unit of analysis first needs to be made clear. The unit of analysis is strongly related to the main research question the research wants to answer (Stake, 1995; Yin, 2009).

From the main research question of this research the extracted unit of analysis that can be the industrialised housing construction company since it is the main focus of the researched phenomenon. With this unit of analysis or “case”, it is seen that the industrialised housing construction company is part of a larger context, namely, industrialised housing construction as a sector. When this is translated to the four basic case study designs of (Yin, 2009) it is noted that for this single research the case study design would be a Single-case Holistic design (Figure 2).

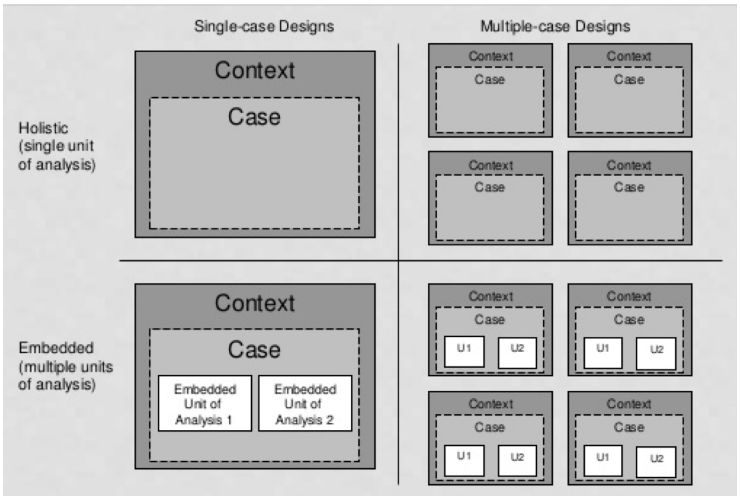

Figure 2: Basic types of case study design (Yin, 2009)

In order to now ensure external validity, this single case study will need a large theoretical basis. However, to create even higher external validity and improve the quality of this research over time, multiple case studies can be performed using the same case study design and protocol at other industrialised housing construction companies. This will transform the case study from a single-case design into a multiple-case design where results can be compared. These studies can all be performed individually and due to the single case study design the multiple outcomes can be generalised (Dul & Hak, 2008; Yin, 2009).

4.2 Case study protocol

In order to increase the reliability of a case study a case study protocol is made. The protocol is intended to guide the research and describe the data collection and analysis methods of a single case (Yin, 2003). For this research, the Case study protocol is formed using theories from the literature review to maximise external validity. The protocol focusses on analysis methods of the data in order to answer the sub-questions set in the research objective. The data gathering methods are also described in order to maximise construct validity. The case study protocol used for this research uses of three data analysis sections: Current situation analysis, Creation of future scenarios and Effects mapping. At the end of the protocol the methods of data gathering is discussed in order to ensure construct- and internal validity.

4.2.1 Current situation analysis

The first step in the case study is that of building a reference case of the current situation in order to compare the changes of future scenarios based on consumer choice on. With the creation of the reference situation sub questions: SQ1, SQ2, SQ3 and SQ4 will be answered.
Since a house is a very complex product and the accompanying process are also very complex a structured analysis is needed. First the complex product of the house is broken down into

several modules following the theory of modularisation where a complex product is split up into manageable subsections based on their use (A.G.F Gibb & Isack, 2003; Hofman et al., 2006, 2009; Veenstra, Halman, & Voordijk, 2006).
After the modularisation, a supply chain and process mapping will be performed as described by (Gardner & Cooper, 2003). From the supply chain and process mappings the case specific performance indicators are extracted in the mappings of the physical- and information flows in the current situation are made clear. These flows are then used to extract the CODPs on different levels using a method developed by (Schoenwitz et al., 2017).
During the last current situation analysis phase, the external effects that are specific for the production technique of the industrialised housing construction company are mapped based on the found external effects categories of (Gann, 1996; Hsieh, 1997; Lu, 2007; Pan et al., 2008).

4.2.1.a Modularization

In the Netherlands the use of product modularization in housing construction has been researched by (Hofman et al., 2006; Veenstra et al., 2006). In housing construction, the functions that the modules are based on are mostly determined by their use. As described earlier in the literature review (Hofman et al., 2006) described housing modularisation based on consumer preference. The modules found were: Floor plan, Interior Finish, Exterior finish, Technical systems and Inner doorways. In a different study focused on consumer preference but also taking into account the ability for change by the consumer in traditional housing construction (Veenstra et al., 2006) found twelve modules in the categories: Core, Built-in, Extensions and Finishes.
For this research a combination of (Veenstra et al., 2006) and (Hofman et al., 2006) will be used adapted to industrialised housing construction. The modules used for the case study are: Structural work, Interior layout, Technical systems, Interior finish, Exterior finish, Kitchen and Bathroom.

Structural work

Based on the work of (Habraken, 1962) the structural work of a house can be seen as the "support" of the house. All load bearing elements are included in this module. Also, the openings for the outside doors and windows are defined in the structural work. The structural work is chosen as a separate module since in most industrial housing construction methods the "support" and "infill" as defined by (Habraken, 1962) are constructed separately. The Structural work can consist of multiple materials and can have multiple production techniques, however, in most industrialised housing construction methods the structural works are produced before and separate of the rest of the modules.

Interior layout

The interior layout is chosen as a separate module since in the production process of industrialised housing construction it dictates most of the other functional spaces in the house. Since in most industrialised housing construction processes the structural work is the load bearing component, the interior layout is constructed of lightweight constructed walls and will form what Habraken defined as the "infill" (Habraken, 1962).

Technical systems
The technical systems include all the technical installations of the house including: Water Electricity, Heating, etc. All the technical systems are counted as one single module even though they can have very different components. The technical systems do not have a separate functional space in the house, but the components are included in other functional spaces such as room heating or water lines in the interior layout walls. But, since technical systems can have a large amount of choice and impact on the process they are counted as a separate module in this research.

Interior finish
In the interior finish module, the cosmetic finish of all walls, floors and ceilings (not finished as standard in other modules) are included. There are many possibilities for the finishing of walls, floors and ceilings to choose from, but there is also the possibility to not include any interior finish in the final product. Since the interior finish is mostly applied separately of other modules it is used as a separate module for this research.

Exterior finish
The exterior finish module includes all the finishing components for the exterior of the structural work. However, due to the number of possibilities offered in sub-components, the components are only included on the higher levels; Exterior wall finish, Insulation, Exterior roof finish, etc. Only the component levels in which choice is possible for the industrialised housing method researched are counted in the module exterior finish.

Kitchen
Since the construction of a kitchen is mostly done in a separate factory from where sub-assemblies are transported towards the final house to be installed. The kitchen is counted as a separate module. In the kitchen module, all components needed to manufacture the kitchen are included but only the ones that include choice options are used for this research.

Bathroom
The bathroom is defined as a separate module since it has a very specific function in the house and can even be preassembled at a separate factory and delivered at the building site or factory as a completed unit. Since there are a lot of choice options in the bathroom and there is a high degree of preassembly possible the bathroom is counted as a separate module. Like the kitchen, the components that include choice options are included in the research.

4.2.1.b Supply chain mapping
For the Supply Chain Mapping the aim is to provide a complete overview of the in- and outbound flows of materials and information from supplier through the industrialised housing manufacturer until the customer or consumer (Gardner & Cooper, 2003). For this first a basic supply chain model is made to get a good view on the positioning of the industrialised housing construction company in the total supply chain. This basic overview is further expanded to a Business scope diagram to determine the boundaries on the mapping and find the basic flows between the actors in the supply chain.
The final mapping of the supply chain will be performed using the SCOR model as provided by the (Supply Chain Council, 2010). The SCOR model is chosen since it is a complete assessment method of Supply Chain Modelling and has a high degree of standardization.

Other deterministic models of Supply Chain Mapping such as the techniques described by (Ishiit, Takahashit, & Muramatsut, 1988; Williams, 1981, 1983) are more detailed Supply Chain Mapping methods that analyses the supply chain very specific (Beamon, 1998). However, for this research a highly specific method will make it harder to generalize the analysed supply chain to other industrialised housing manufacturing manufacturers. With the SCOR model this generalization is possible through the standardized reference model.
The SCOR model for this case study is set up in two phases. The first phase will analyse the performance attributes of the industrialised housing construction company while in the second phase, the supply chain itself is mapped using a thread diagram following the SCOR methodology.

Performance attributes

Performance attributes in the SCOR model are used to express the strategic focus of a company. Performance attributes cannot be directly measured but it is used to express the strategic direction, the accompanying metrics are used to measure the ability for the company to achieve these attributes. Using the SCOR model, the performance attributes are categorized in five different categories (Table 4).
The categories together form the strategic main focus of the company and this should be represented in the focus of company. The categories described by the SCOR model are: Reliability, Responsiveness, Agility, Costs and Assets.

Table 4: SCOR performance attribute categories

Attribute category	Attribute focus	Level 1 metrics
Reliability	Customer focused	Perfect Order Fulfilment
Responsiveness	Customer focused	Order Fulfilment Cycle Time
Agility	Customer focused	Upside Supply Chain Flexibility Upside Supply Chain Adaptability Downside Supply Chain Adaptability Overall Value at Risk
Costs	Internally focused	Total Cost to Serve
Assets	Internally focused	Cash-to-Cash Cycle Time Return on Supply Chain Fixed Assets Return on Working Capital

Thread diagram

The next step of the SCOR model is the mapping of the processes within the industrialised housing construction company on level 2 score process elements (Table 5). The mapping will identify the stakeholders in the supply chain and the process links between them. For the mapping, all the processes elements are defined in terms of four categories: Plan, Source, Make and Deliver.

Table 5: SCOR level 1 Process categories and level 2 Process elements

Level 1 Process category	Level 2 Process element
Plan All the process steps associated with the planning and scheduling for the operation of the supply chain	**P1** Plan supply chain **P2** Plan Source **P3** Plan Make **P4** Plan Deliver
Source Ordering, scheduling and receiving of goods and/or services	**S1** Source stocked product **S2** Source Make-to-Order Product **S3** Source Engineered-to-Order Product
Make Change in physical shape of the product or the combining of multiple items into one or more different items.	**M1** Make Made-to-Stock Product **M2** Make Made-to-Order Product **M3** Make Engineer-to-Order Product
Deliver Processing of goods and services according to the customer order and delivery to the customer	**D1** Deliver Stocked Product **D2** Deliver Make-to-Order Product **D3** Deliver Engineered-to-Order Product **D4** Deliver Retail Product

4.2.1.c Process mapping

Besides the general overview that the Supply Chain Mapping provides, a more detailed overview is needed when it comes to the introduction of customer or consumer choice in the process and the accompanying information flows. Therefore, Process mapping (Gardner & Cooper, 2003) is used to generate a detailed information flow map from consumer or customer through the industrialised housing manufacturer to the suppliers. The Business Process Model and Notation (BPMN) (Dijkman et al., 2011) is a very suitable tool for this since it will generate a chronological flow of the decisions and impact of these decisions per stakeholder. By using the BPMN as a Business Process Mapping tool the different involvements of the stakeholders and the effect of these stakeholders on the process will be made visible and in a more detailed way as the SCOR model. By analysing the information stream map created by the BPMN the complexity of the information needed during the process will be made clear. The BPMN will later be used to see where in the supply chain consumer choice has an impact on the rest of the information flows and if it can be realised using the current information carriers.

BPMN illustrates all the different actors within the supply chain in different “lanes” and puts the actions of information flow in a chronological order. The actors to be used in the BPMN are the same as defined in the business scope of the supply chain mapping. A side note for the BPMN of is that the BPMN is only focussed on the information streams that result in a physical flow for this research and therefore, the financial information streams such as invoicing are left out of the mapping.

4.2.1.d CODPs mapping

the supply chain and process maps are now used to determine the positioning of the Customer Order Decoupling Points (CODPs) for the industrialised housing construction company. The CODP is the point that splits the supply chain into two parts: an upstream forecasting and a downstream customer order. In the literature, there are many definitions of the CODP however, for this research the CODP will be defined as the point in the supply chain where the product is linked to a specific customer or consumer order. (Hoekstra & Romme, 1992) define five basic logistical supply chain strategies that determine the placement of the CODP: Buy(Engineer)-to-order, Make-to-order, Assemble-to-order, Make-to-stock and Ship-to-stock. A simple representation of each of these five strategies is shown in Figure 3.

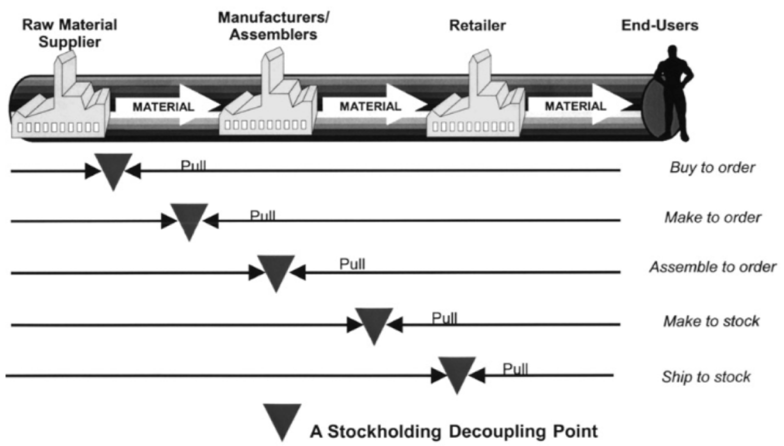

Figure 3: Supply chain strategies and decoupling points (Hoekstra & Romme, 1992)

Buy(engineer)-to-order

Nothing is kept in stock and everything is specially made for the customer or consumer to their specifications or preferences. The whole project is carried out for that one specific customer or consumer.

Make-to-order
Only raw materials and components are kept in stock. When a customer or consumer order is received, the product is made from these raw materials.

Assemble-to-order
Subassemblies or elements of the final product are stocked and once a specific customer or consumer order is received, the requested product is assembled from these subassemblies or elements to the customer or consumer preferences.

Make-to-stock
Products are pre-manufactured and stored in a centralized warehouse from where the products are distributed once a customer or consumer orders them.

Ship-to-stock
Products are pre-manufactured and distributed to (many) local stock points from where they are directly sold and distributed to customers or consumers.

In order to strategically position the CODP, a balance between product properties, market factors and process factors is required (Olhager, 2003). For this research in order to later be able to find the influence of consumer preferences, the positioning of the CODPs will be linked to the level of consumer choice or level of available customisation.
(Barlow et al., 2003) adjusted the Standardisation-Customisation continuum model of (Lampel & Mintzberg, 1996) by using the concept of the Customer Order Decoupling Point and creating a housing specific supply chain model based on consumer choice. In this model, he did not only focus on the physical flow of materials, but also took in consideration the design function (Figure 4). In the model, there is a distinction made where the consumer is taken up into the process. White process elements are standardized elements while the shaded elements are customized by the consumer.

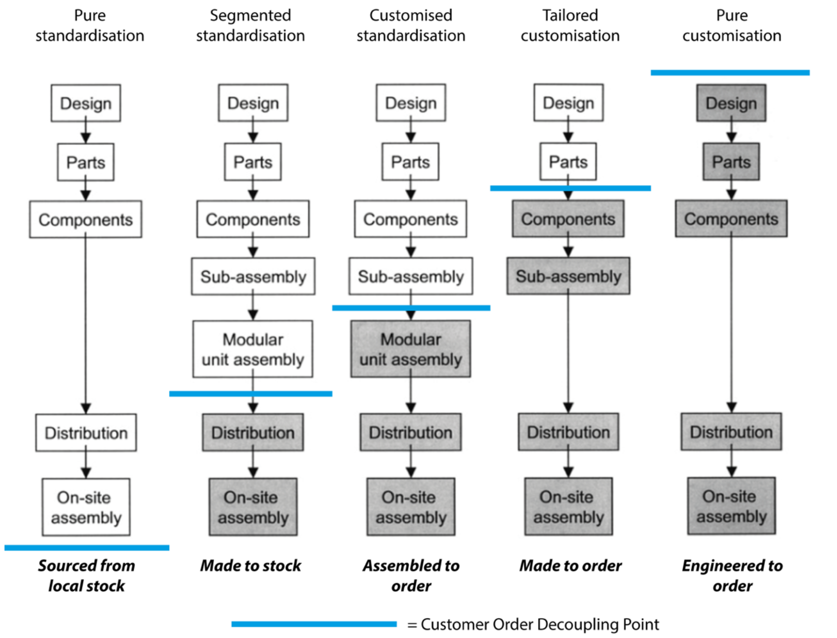

Figure 4: House building supply chains (Barlow et al., 2003; Hoekstra & Romme, 1992)

At Pure customisation, requirements of the consumer are taken into account at the design stage. This is comparable when a product is “Engineered-to-order” according to (Hoekstra & Romme, 1992). This can be compared to a self-build house, where the house and location are completely open to the preferences of the consumer. The other end of the spectrum shows no consumer intervention at all. This is a completely standard house where the design all the way to the final location of the house are completely predefined. This can be compared to “Sourced from local stock” as defined by (Hoekstra & Romme, 1992).

For the segments in-between the two extremes, subtle differences change the position of the CODP. For segmented standardisation houses are built on request but no changes to the design are possible. This can be compared to the Made-to-stock production system. The house is only build from standard thought-out parts but is not present at the final location yet. The CODP will be just before the house is built on the final construction site or in a factory and then transported to the final construction site. For customised standardisation, a little more consumer influence is possible. However, the consumer can only choose from predefined options that are transported to the final construction side where they are assembled. However, the construction can also take place offsite where modules are pre-build and assembled before they are distributed to the final location. This method can be compared to Assembled-to-order. Tailored customisation takes it one step further where the modular sections are completely open to consumer preferences but are assembled from standardized parts. This can be compared to the Made-to-order production system.
This model of (Barlow et al., 2003) provides a good general overview of the supply chain models in house building on an aggregate level of consumer choice, but it does not take into consideration the possibilities of consumer choice on lower levels in the supply chain, or underlying processes that can lead to different CODPs. Therefore, the SCOR and BPMN models are used as inputs for a CODPs mapping on three different levels (Figure 5)(Schoenwitz et al., 2017).

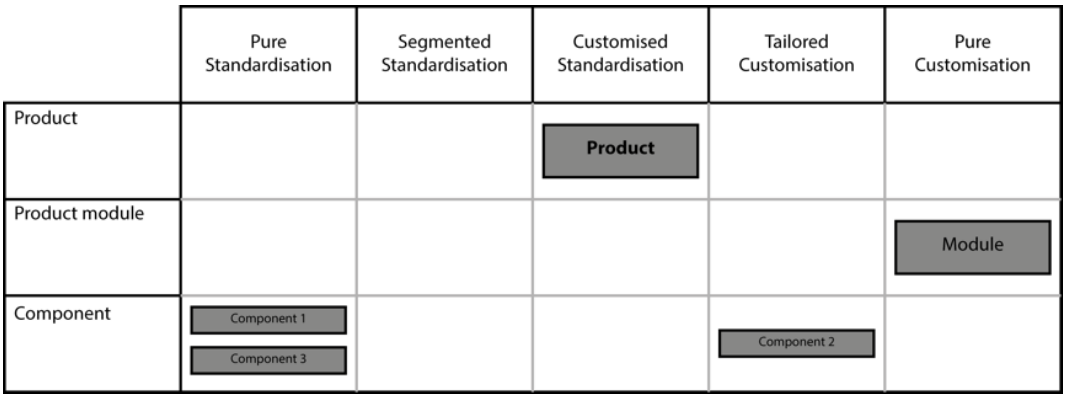

Figure 5: CODPs mapping example (Schoenwitz et al., 2017)

The CODP is mapped on the Product level where the end product (the house) according to the possible changes in the final product is the subject. This can be compared to the mapping as suggested by (Barlow et al., 2003). The second level mapping consists of the Product module mapping where the CODP of the individual product modules are the subjects. The lowest level of the CODP mapping will separate the product module in the previously defined components. By combining the three levels a complete picture of the current positioning regarding the CODPs is created.

4.2.1.e External effects mapping

Besides the effects on the process, this research also focuses on the external effects of industrial housing construction. As discussed in the literature review, industrialised housing construction can have multiple external effect outside of the business process. The exact effects are different for each method of industrialised housing construction. However, during the literature review multiple sources confirm five categories of external effects (Gann, 1996; Hsieh, 1997; Lu, 2007; Pan et al., 2008): Construction time, Construction cost, Quality, Safety and Environment.

Using these five categories the positive and negative external effects for the industrial housing construction method under review can be explained as compared to traditional housing construction. With the mapping of the external effects, SQ4 can be answered and the current situation analysis will be finished. All the gathered information and insights into the industrialised housing construction company is reported in the current analysis of the case study and used later to assed the future scenario created in the next phase of the case study.

4.2.2 Future scenario creation

The second phase of the case study focuses on the creation of the comparison situation. The future scenario used in the cases study will be based on consumer preferences. However, because the consumer preferences are too brought to incorporate in the supply chain all at once, the consumer preferences are bundled into the product modules for the specific industrialised housing construction company. By extracting the module with the highest preference score, the most feasible positioning of the CODPs based on consumer preference will be found (Figure 6).

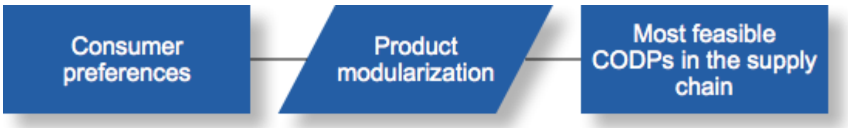

Figure 6: Future scenario creation based on consumer preferences

4.2.2.a Consumer preferences

In order to base the placement of the CODPs on consumer preferences, these preferences have to be known. As seen in the literature review a vignette based survey was conducted in the Netherlands where (future) house owners provided their relative importance against 34 housing components (Figure 7)(Hofman et al., 2006). Since for this research the influence of consumer preference is more important as the preference itself the data collected by (Hofman et al., 2006) is used to create the future scenario. However, since these 34 preference indicators cannot be directly translated to CODPs, the preferences are first categorised based on the product modularisation.

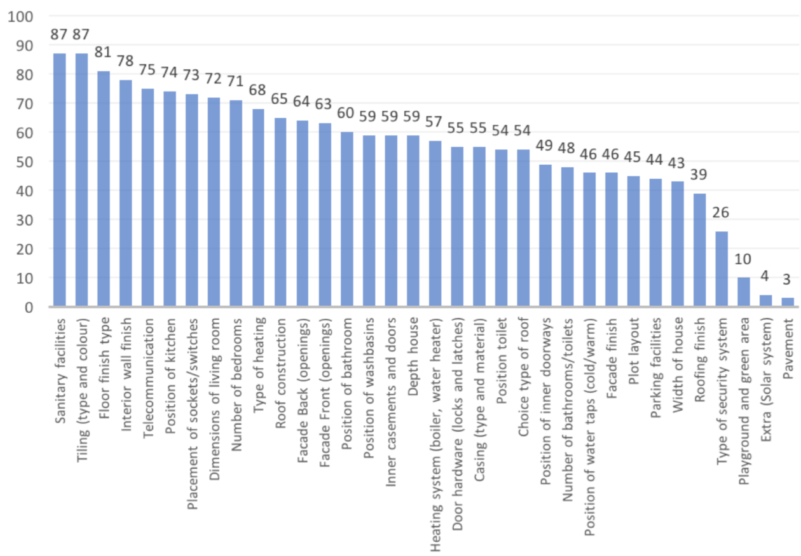

Figure 7: Relative importance of customisation (Hofman et al., 2006)

4.2.2.b Product modularisation

In order to translate the expressed consumer preferences of (Hofman et al., 2006) into CODPs that can be compared in the model created for the current situation, the preferences are categorised per product module. This categorisation is based on the product modularisation of the industrialised housing construction company under study and their definition of the modules. Therefore, the preferences are transformed using a relation matrix as shown in Table 6. As can be seen in the example, multiple product modules can be impacted by a single housing element preference indication. It can also be true that no module is impacted by the preference indicated because it is out of the scope of the industrialised housing construction company. This can for example be the case with “Playground and green area”. The housing constructor places the house on the site it gets from the customer. The customer can determine this factor, the industrialised housing construction company can mostly not.

Table 6: Consumer preference modularisation example

Housing components

Pavement	Extra (Solar system)	Playground and green area	Type of security system	Roofing finish	Width of house	Parking facilities	Plot layout	Facade finish	Position of water taps	Number of bathrooms/toilets	Position of inner doorways	Choice type of roof	Position toilet	Casing	Door hardware	Heating system	Depth house	Inner casements and doors	Position of washbasins	Position of bathroom	Facade Front	Facade Back	Roof construction	Type of heating	Number of bedrooms	Dimensions of living room	Placement of sockets/switches	Position of kitchen	Telecommunication	Interior wall finish	Floor finish	Tiling	Sanitary facilities	***Product modules***
					×		×					×					×						×											Structural work
										×	×							×		×					×	×		×						Interior layout
	×		×						×							×								×			×		×					Technical systems
															×			×												×	×			Interior finish
				×				×						×	×						×	×	×											Exterior finish
									×										×									×		×	×	×	×	Kitchen
									×	×			×						×	×										×	×	×	×	Bathroom

4.2.2.c Most feasible CODPs in the supply chain

With the preferences of the consumer modularised for the industrialised housing construction process, the most feasible CODPs in the supply chain based on consumer preferences can be extracted. For this, the relative importance is combined with the modularisation matrix by using the generational variety index (GVI) of (Veenstra et al., 2006). The GVI indicates the components that are most probably subject to change over time. The GVI is used as an indication for the amount of redesign needed in the current process to satisfy the needs of the market. In order to estimate the GVI, the expressed relative importance of (Hofman et al., 2006) is filled in in the modularisation matrix. This creates the GVI matrix of the specific industrialised housing construction process based on consumer preferences. By adding all the GVI scores per module (the sum per module column of the GVI matrix) the absolute importance GVI is calculated. The higher the score, the more likely the module is impacted by consumer preference. In order to translate the absolute GVI in to CODPs for the supply chain the Relative importance GVI is calculated. The relative importance GVI is the GVI per module divided by the total sum of all the modules GVI’s divided by 100:

$$GVI_{relative} = \frac{GVI_{module}}{\sum GVI_{module}} \times 100$$

The relative importance gives a clearer view on the importance per module in the supply chain. The module with the highest $GVI_{relative}$ needs the most attention in order to satisfy the consumer preferences.
In order to translate the $GVI_{relative}$ scores of the modules to CODPs, the CODPs are mapped in a most feasible matrix (Figure 8). This matrix is later used to compare the current situation to the most feasible situation. The GVI scores determine if there is a high, medium or low preference for customisation. The ideal situation will be where all the modules offered in the product fall within the white area of the matrix.

In order to determine the most feasible placement of the CODPs, the modules are mapped in the matrix based on their individual preference score (Figure 8). The determination of the most feasible CODPs based on the preference is the concluding step of the future situation based on consumer preferences.

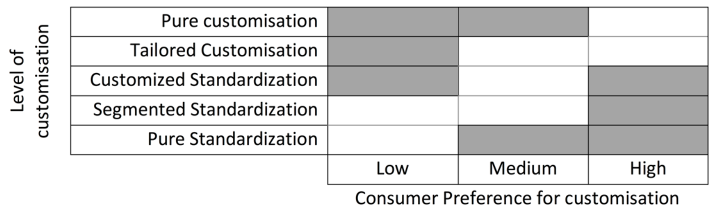

Figure 8: Most feasible CODPs matrix (Schoenwitz et al., 2017)

4.2.3 Effects mapping

In the third and final phase of the case study, the changes between the current and future situations are extracted in order to find the influence of consumer preference on the process of industrialised housing construction. The effects of consumer preference are mapped in two stages, first the supply chain effects are mapped. And secondly, the external effects of introducing consumer choice are determined.

4.2.3.a Supply chain effects

In order to find the influence consumer preference has on the supply chain of industrialised housing construction, the current situation mapping of the CODPs and the most feasible situation based on consumer preferences are compared (Figure 9).

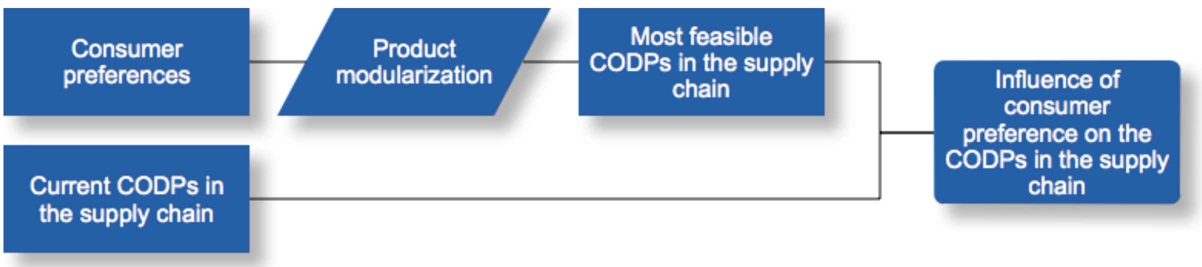

Figure 9: Comparison on Customer Order Decoupling Points (CODPs) in the supply chain

By comparing the current positioning of the CODPs with the most feasible placement of the CODPs on module level, misalignments can be determined. If misalignments are found in the current model of CODPs the model is traced back on the components level in order to find the exact misalignment. The misalignment can have two reasons; The process needs to be reconfigured, or the marked positioning of the product is inadequate (Figure 9).

Process reconfiguration is discussed during the supply chain effects. The internal process effects will change the positioning of the CODPs in the process. During the market repositioning, the external effects are leading. The external effects of the process change the possibility of most feasible CODPs positioning and the preferences of the consumer. In the next section of the case study.

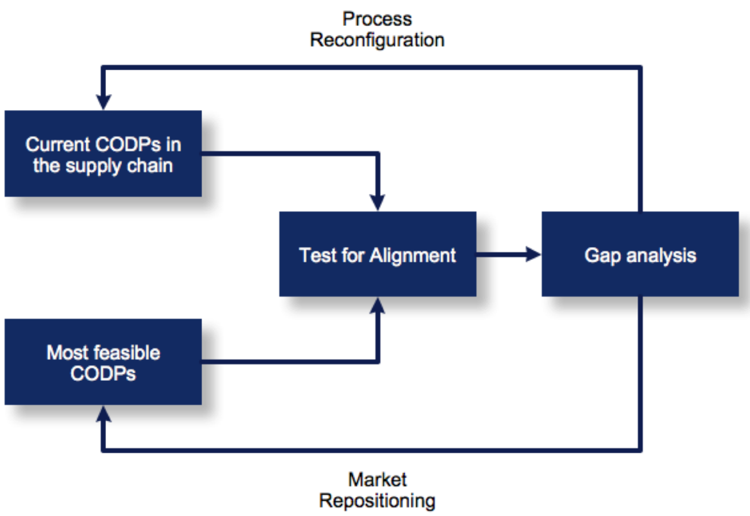

Figure 10: CODP alignment test (adjusted from (Schoenwitz et al., 2017)*)*

4.2.3.b External effects

For the influence on external effects a relation matrix as shown in Figure 11 will be used in order to analyses the relations between the positioning of offering choice on the CODPs and the external effects. On the X axis of the matrix there are the product modules as defined in the product modularisation. On the Y axis, there are the external effects determined in the current situation analysis.

For the external effects matrix, the preliminary external effects analysis of the current situation analysis is used in order to construct the Y axis effects per category. In order to find the effects per product module, the required process change from the previous supply chain effects is compared per product module, and the accompanying external effects per product module are extracted using the matrix. In order to determine the effects per product module and the total external effects of introducing consumer choice to the process, a more detailed description is made per external effect category where the exact effects are described and the interrelations between the effects are examined.

Product modules

External effects	Structural work	Interior Layout	Technical systems	Interior finish	Exterior finish	Kitchen	Bathroom
Construction time							
Effect 1							
Effect n							
Construction Costs							
Effect 1							
Effect n							
Quality							
Effect 1							
Effect n							
Safety							
Effect 1							
Effect n							
Environment							
Effect 1							
Effect n							

Figure 11: External effects relations matrix example

4.3 Data collection

In order to perform the case study according to the case study protocol, data has to be collected from the case. In order to maximise the quality of the case study, the construct validity will have a large effect. (Yin, 2003) describes multiple methods of data collection in order to keep the construct validity as high as possible. Two methods have been identified for this qualitative case study. To start with multiple sources of evidence are used for the collection of data and all these sources of data are converging towards the same end goal. Besides this, triangulation is used in order to compare the outcome of multiple sources and combine them into the best information as required to perform the case study.

4.3.1 Convergence of evidence

As described by (Yin, 2009) evidence or data for case studies can come from six sources: documents, archives, interviews, direct observations, participant-observations and physical artefacts. In order to maximise the quality of the research, evidence collected should come from multiple sources. However, a prerequisite for multiple sources of data should be that they all converge to a single goal.

For this research, due to the limited time and researchers available, four evidence collection methods have been selected (Figure 12). However, these data collection techniques are carefully chosen in order to ensure maximum quality and converging evidence streams. Below an explanation of the four evidence collection methods is given:

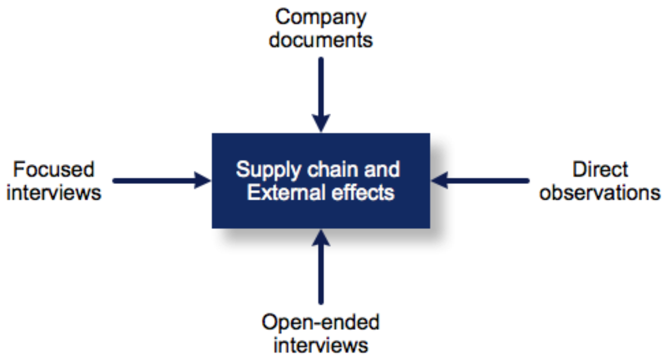

Figure 12: Evidence convergence

Company Documents

The first sources of evidence are formal- and informal company documents. Basic information about the process and choice options in the current process are taken from public and non-public company documents. Company documents can provide a basic knowledge about the products and processes of the industrialised housing construction company under review.

Direct observations

The second source of information are direct observations within the industrial housing construction company itself. However, also direct observations are done using company visits at suppliers and customers of the industrialised housing construction company. Direct observations are primarily used as a direct source of evidence to the researcher since they can give a good overview of the process steps involved and external effects.

Open-ended interviews

As a third method of evidence collection open-ended unstructured interviews are a good source of unbiased information about the external effect of the process and the running of the process. Open-ended interviews are held within the industrialised housing construction company itself and the suppliers. If possible even open-ended interviews can be held with the customers or consumers of the industrialised housing construction company. Open-ended interviews used as a preliminary data gathering method to form the focussed interviews and as a secondary source of information during the direct observations.

Focussed Interviews
The last and most important source of evidence for this case study are the focussed interviews. The focused interviews are held with different stakeholders throughout the supply chain to get a full picture of the current process and the exact external effects of this process. The focused interviews will be semi-structured to keep the interview on topic, but reduce researcher bias. The semi-structured interviews also provide the best solution to gain a deeper understanding of the external effects in industrialised housing construction (Kallio, Pietilä, Johnson, & Kangasniemi, 2016). A list of the interviews is made to show who has been interviewed and where in the supply chain this interview can be placed.

4.3.2 Triangulation
Using multiple sources of converging evidence can be increased by the use of triangulation methods (Dul & Hak, 2008; Yin, 2009). Triangulation can be done in four categories: Data triangulation, investigator triangulation, theory triangulation and methodology triangulation. For this case study, a combination of data and investigator triangulation is used. The evidence as described previously is collected through multiple sources. These four sources are compared to each other in order to find if the multiple sources of evidence provide the same conclusions. This is not only done between the methods of evidence collection, this is also done within the evidence collection method. Multiple interviews are compared in order to find if they give the same answer and conclusions. The second method of triangulation used is investigator triangulation. The evidence collected for the case study is collected by one single investigator. However, the evidence in the report is always checked by multiple investigators of the company and throughout the stakeholder to check if the written statements and supply chain models used in the case study are correct.

By ensuring multiple sources of evidence provide the data for the case study protocol and by keeping record of the evidence sources, the quality if this research is kept as high as possible with the available researches. Also, the evidence collected is converged into a single goal though triangulation of data. This all has to ensure maximum construct validity possible.

PART B – Research execution

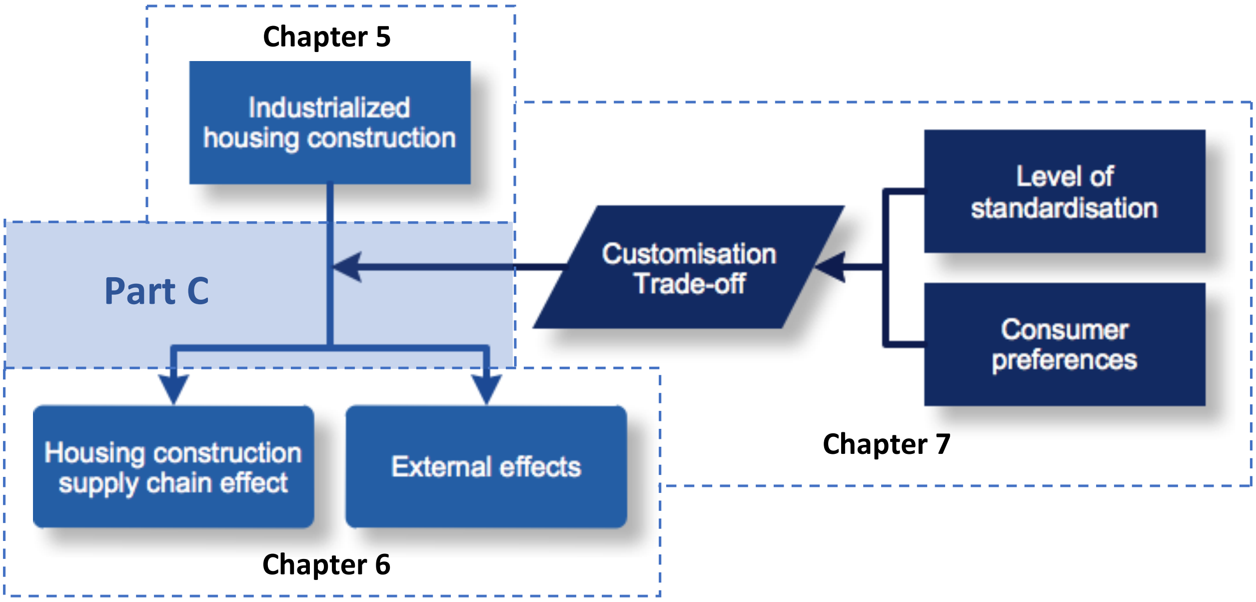

Figure 13: PART B - Research execution

During the second part of this report, the previously developed case study design will be executed at an industrialised housing construction company following the conceptual framework (Figure 13). In chapter 5 a case description is given highlighting the chosen case, CascoTotaal, and the method of industrialised housing construction performed by CascoTotaal. In chapter 6, the current supply chain and external effects are analysed for CascoTotaal based on the case study protocol. Lastly, in chapter 7 the trade-off between consumer preferences and standardisation is made for CascoTotaal by creating a future scenario for the product and process. This future scenario will be compared to the current situation in the third part of this report in order to find the effects of customisation on the process of CascoTotaal.

5 Case description

For the execution of the case study as described in the case study protocol, a real-world situation is needed for the unit of analysis. The real-world situation should be related to the end goal of this research and provide significant evidence for the case study to be performed. For this research, the case or unit of analysis as described should be an industrialised housing construction company in The Netherlands. CascoTotaal is selected for this research as the unit of analysis since the research is commissioned by CascoTotaal. CascoTotaal is an industrial housing construction company located in Zeeland, The Netherlands. CascoTotaal is suitable as a case since it is a serious player in the industrialised prefabricated off-site manufactured housing sector. By using CascoTotaal for the case study the results will very likely contribute to the knowledge building of consumer preference influence and its impact on the supply chain and external effects in the industrialised housing construction sector and its suppliers (Dul & Hak, 2008). Information needed for the case study was collected using the four collection methods described in the case study protocol throughout the supply chain of CascoTotaal and multiple stakeholders as can be seen in Appendix I.

5.1.1 Company profile

During this research, a case study is used to examine the supply chain of a prefabricated housing construction company in The Netherlands. For this case study CascoTotaal is used as the construction company. CascoTotaal is based in Terneuzen and produces prefabricated concrete based modular houses since December of 2015 (a detailed description of the production method is described in section 5.1.2). For this case study one of the standard products offered by CascoTotaal is taken as a reference. The chosen product is the Spero 1 prefabricated house (Figure 14). The Spero 1 consists of two separately constructed sections and a roof module that are connected on the final construction site (on-site) to create a two-bedroom single family house.

Figure 14: Spero 1 single family two-bedroom home

5.1.2 Production process

The production process of CascoTotaal can be split up into three separate types of work. The first type is the structural work where all the supporting concrete construction work is performed. The second type of production is the finishing work where the structural sections are finished into a complete house. The last type of work performed in the production process of CascoTotaal is the construction site work in which all the activities that happen on the construction site itself (on-site work).

Structural work

For the structural work of the houses CascoTotaal has a unique 3D concrete pouring system that can fabricate the structural elements of the building in three sections: walls and ceiling, floor and closing wall. The largest section of these three, the walls and ceiling element *(Figure 15)*, is poured from concrete in a for CascoTotaal designed and build 3D casting system. All internal parts such as the pipe-work are all prepared in the casting before the concrete is poured. In this way, when the element is released from the casting no extra work on the walls and ceiling should be needed.

Figure 15: Walls and ceiling element

For the floor element, plumbing and floor heating are also installed in the floor before installation. The production of the three structural work sections takes one full day. The three parts are combined after the production day. The floor is moved inside the walls and ceiling section and the closing wall is welded into place to finish off the Structural work and to form the full structural shell of the house. A house can consist of multiple structural work sections, in this case multiple units are combined on the final construction site.

Finishing work

After the structural works, the structural shell is moved to the finishing factory building where there are two lines of ten stations that transform the structural shell into the final product. The finishing factory is a fully enclosed factory where during ten stages different operations are performed on the structural shell under fully conditioned circumstances (Figure 16).

Figure 16: Finishing work on the carousel

In the finishing factory, the production line has a takt time of one day per stage. This means that after every work day the unit will move to the next stage using a roller system (carousel). The two production lines of ten stages can be rearranged in two different shapes.

The line can be a U-Shaped parallel carousel where the Structural shells are coming on to the carousel via two parallel doors and leave the carousel on two separate parallel doors as depicted in Figure 17. This production line configuration would be used if the two production lines produce the same units since the materials needed per production station can be concentrated in a single location of the factory. The configurations in production lines is created due to a limitation in factory space. Due to the limitations of the building the lines are U-shaped. In a larger building this situation would be a parallel I shape. Due to the limitations of the building the movement of stage A5 to A6 and the movement from B5 to B6 has to happen at the same time since A5 cannot overtake B5. Therefore, the total production time on both lines has to be the same.

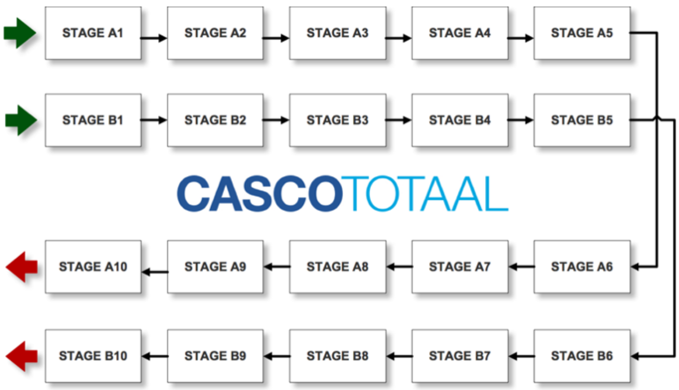

Figure 17: Parallel U-Shape production

these limitation in movement can be taken away by configuring the production lines in a second way. The lines can be arranged as two separate U-shapes running from the outside to the inside as depicted in Figure 18.
However, since the outside stages (A1-A5 and B1-B5) now have a different positioning of the material stocks, this production line configuration is only used if the two production lines produce different products with different takt times.

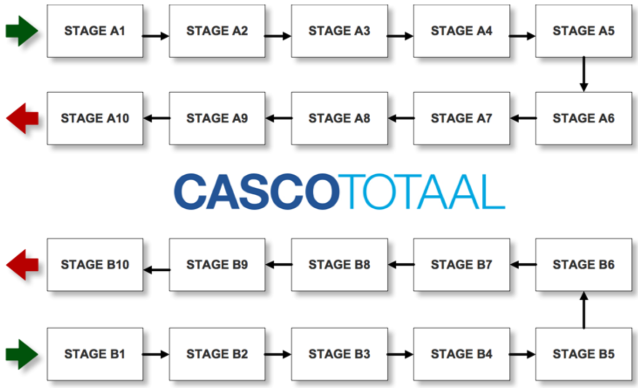

Figure 18: Separate U-Shape production

For the finishing factory, different subcontractors are used for the actual work. The role of CascoTotaal in the finishing factory is that of facilitator of the sub-contractors. CascoTotaal facilitates the factory building and the stream of building materials needed to finish the end product by the sub-contractors. CascoTotaal is not responsible for the actual construction of the house, but is responsible for the smooth running of the finishing lines.

Construction site work

On the final construction site, far less work has to be performed as compared to the traditional housing construction method. Before the modules can be placed piles have to be placed in the ground as a foundation and made perfectly level in order to support the modules. Also, the connections for the utilities such as electrical connections, water and plumbing are installed during the groundwork. After this the modules need to be transported (Figure 19) from the factory to the construction site by low-loading trailer and put in place by a movable crane (Figure 21). The modules do not require a mechanical linkage if the total construction is lower than 4 modules in height (Figure 20).


Figure 19: Module being prepared for transport


Figure 20: Connection of multiple modules


Figure 21: Modules being put in place on the construction site

After the placement of the modules on the construction site they are connected to the utilities. Once connected, the house is ready to be lived in and handed over to the owner. Other surrounding work on the construction site such as the finishing of pavements and garden can start as soon as the house is in the final position.

6 Current situation analysis for CascoTotaal

Now that the case for this research has been described in the previous section, the execution of the case study can start following the case study protocol. The case study starts with the analysis of the current situation of the supply chain, the customer order decoupling points and the external effects. The current analysis starts with the description of the modules as they are in effect at CascoTotaal. These modules are used for the rest of the current situation and for the later analysis phases of the case study. After the modularisation, the current supply chain is mapped using multiple levels of detail. The performance attributes are also mapped during the supply chain analysis as part of the SCOR model. To give a more detailed view of the information streams and stakeholder involvements in the decision making surrounding consumer choice, a process mapping is made using the BPMN method. The supply chain mapping and process mapping both converge in the mapping of the current CODPs on three levels. The last step in the current situation analysis will include the external effects mapping.

6.1 Product modularisation

To start the case study at CascoTotaal, the product modularisation is made by defining the product module categories of the case study protocol: Structural work, Interior layout, Technical systems, Interior finish, Exterior finish, Kitchen and Bathroom for the Spero 1 single family house. Below a short description of the components within and application of these modules at CascoTotaal is given:

Structural work

In the specific production process of CascoTotaal the structural work includes the concrete element which can be changed in all three dimensions (length, width and height) as required or chosen in the final product by customer. Included in the Structural work module are the reinforced concrete (concrete and steel rebar reinforcement). Also, the mounting hardware needed for the lifting and placement of the final unit are included in the structural work. Lastly the installation materials needed in the perimeter walls and floors such as electrical piping and heating pipes are included in the structural work module.

Interior layout

During the production phase at the finishing factory of CascoTotaal the interior layout has its own separate station on the production line. The interior walls are made using a light weight metal stud frame construction. These walls are easy to place and can be placed at any location within the house to create a very flexible interior layout. The walls consist of metal profiles that are fixated to the structural work and then closed using gypsum board panels.

Technical systems

Included in the technical systems module are the: heating system, electrical system, water system and ventilation system. All these separate systems are bundled together in one module because even though their function being very different, their way of integration in the house are very similar and they are all constructed by the same subcontractor.

The electrical, water and ventilation system consist of the same components in every Spero 1 house CascoTotaal makes. However, for the heating system, there is the possibility for floor-, electrical- or infrared heating to choose from by the customer.

Interior finish

In the interior finish module for CascoTotaal all the interior finishes for the floors, walls and ceilings are included except for the kitchen and bathroom where tiling is applied on the floor and walls separately. At the moment, the ceiling is spray finished and the walls have an interior finish called "wall paper ready". This means that the walls get a flat concrete finish ready for wallpaper to be applied by the consumer, but no liveable finish is applied during the production process to the walls except for the kitchen and bathroom. For the floor finish the kitchen and bathroom gets a tile finish in their own separate module, all other floor finishes are not included as standard in the production process of CascoTotaal at the moment.

Exterior finish

For CascoTotaal, the exterior finish module consists of all the components that are attached to the concrete structural work in order to finish the exterior of the house. First this is the insulation that is placed between the structural work and the exterior wall (façade) finish. The exterior wall finish has multiple options to choose from in different categories. However, the exact finish is not discussed in this research and the finishing of the exterior walls is one component in the module. The same is true for the exterior roof finish, that is also included in the exterior finish module. The last component in this module are the window- and door framings. There are multiple options to choose from but, these options are also counted as one component for this research because the exact component is of less importance to the process.

Kitchen

The kitchen module for CascoTotaal includes all the cabinets, counter tops and appliances as they are supplied by a separate kitchen manufacturer per house. These can be configured to the consumers liking within certain predefined limits at the designated kitchen supplier. The kitchen is than build at the kitchen factory and transported in separate sub-assemblies to the finishing factory of CascoTotaal. At the finishing factory, the kitchen is assembled in the structural unit. Besides the sections supplied by the kitchen factory, the tiling in the kitchen is also included in the kitchen module since these are chosen by the consumer at the same time the kitchen is configured. In the finishing factory, the tiling is performed first before the kitchen is assembled in the structural unit.

Bathroom

In the concept of CascoTotaal the entire bathroom can be a prefabricated unit build and finished at a separate factory. The bathroom is configured at the bathroom supplier and transported as one single unit to the finishing work factory of CascoTotaal. The bathroom unit includes all the bathroom sanitary fitting like a: bath, shower, sinks and toilet. Also, the; tiling, cabinets, technical systems and accessories are included in the prefabricated bathroom unit. At the finishing factory, the unit is placed in the structural work and connected to the required installations of the other technical systems. However, the bathroom can also be configured in the same way the kitchen is build, but the separate components as described above stay the same, only the construction of the bathroom is moved from a separate factory to the finishing factory of CascoTotaal.

A summarizing overview of the modules and components per module for the Spero 1 single family house at CascoTotaal is given in Table 7.

Table 7: Modularisation overview

Structural work	Interior layout	Technical systems	Interior finish	Exterior finish	Kitchen	Bathroom
- Mounting hardware - Rebar - Installation materials - Concrete	- Metal stud wall construction o *Metal profiles* o *Gypsum board*	- Electric - Water - Heating - Ventilation	- Floor finish - Interior wall finish - Ceiling finish	- Insulation - Exterior wall finish - Exterior roof finish - Window- and doorframes	- Counter tops - Cabinets - Tiling - Appliances	- Tiling - Cabinets - Sanitary fittings - Technical systems o *Heating* o *Ventilation* o *Electric* o *water* - Accessories

6.2 Supply chain mapping

For the supply chain mapping of CascoTotaal, multiple levels of detail are used. Starting with a basic supply chain model. The basic supply chain model will then be transformed in a business scope model to gain a higher level of detail. The business scope model will also define the boundaries of the supply chain to be mapped in the highest level of detail by the SCOR model. The mapping of the supply chain is based on direct observations at CascoTotaal and its suppliers in combination with semi-structured expert interviews with stakeholders throughout the supply chain, as can be seen in Appendix I.

6.2.1 Basic supply chain of CascoTotaal

To start the mapping of the supply chain, first a basic material flow schematic is made for the supply chain of CascoTotaal (Figure 22). This basic material flow model is set up as a starting position for the rest of the supply chain mapping using the SCOR model and BPMN mapping.

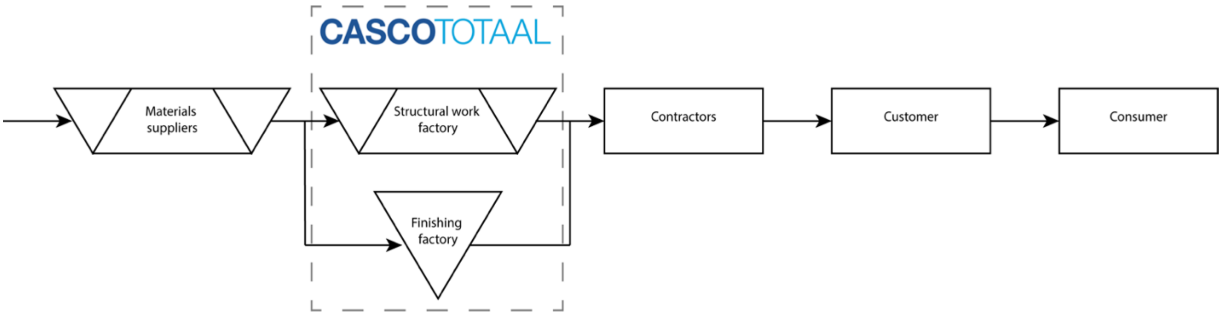

Figure 22: Basic supply chain model of CascoTotaal

Looking at the positioning of CascoTotaal, it is seen that the only inflow of physical products is from its materials suppliers. These materials suppliers have an inbound stock of materials and an outbound stock of materials as a buffer for their production and changes in demand. The suppliers supply materials for the structural works factory and the finishing factory. Materials needed at the structural works factory are stored temporarily in a local stock at the structural works factory before they are needed for the construction of the structural work. After construction, the structural work modules are stored until the concrete is fully cured and the unit is needed at the Finishing factory. The materials supplied to the Finishing factory are stored in a local inventory until the materials are needed by the different contractors.
The finishing factory as incorporated in the process of CascoTotaal does not use the products they receive from the materials suppliers but act as a warehouse for the different contractors. The contractors build the house, from materials directly supplied by the Finishing factory's

own inventory. Therefore, the contractors do not need an inventory themselves. The completed housing units are then transported towards the final location as designated by the customer. The customer takes official ownership once the house is placed on the final location and completed. After an inspection, the consumer receives the key directly form the customer.

6.2.2 Business scope diagram

From the basic material flow supply chain of CascoTotaal, the supply chain can be mapped in more detail. However, in order to create a detailed supply chain mapping, boundaries for the mapping process are needed. This is done by expanding the basic supply chain to a business scope diagram. The stakeholders are expanded and the information flows between the different stakeholders are added to the diagram as depicted in Figure 23.

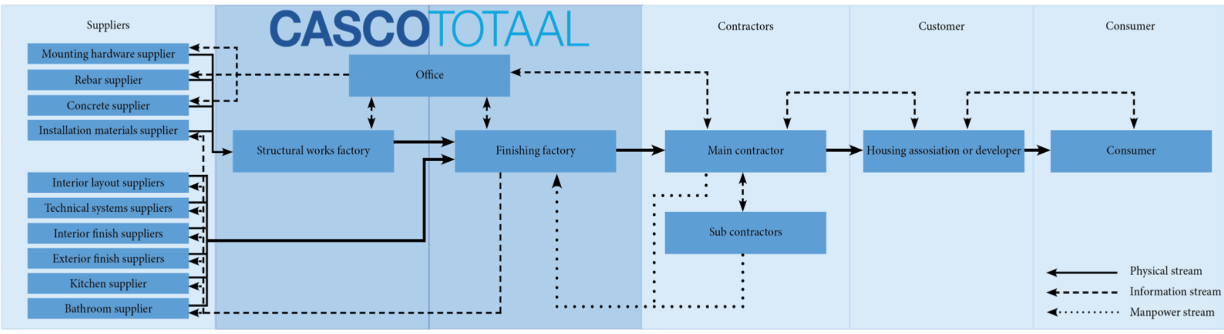

Figure 23: Business scope diagram

6.2.2.a Actors in the business scope diagram

To start the analysis of the business scope diagram, the actors that fall within the scope of this research are identified. Since this research focuses on the supply chain impact of industrialised housing construction with the introduction of consumer choice, the consumer has to be included in the business scope diagram. The consumer is the end point of the supply chain since the process of CascoTotaal stops once the house is handed over to the consumer. When working backwards from the consumer to CascoTotaal, there are multiple actors in between. The first actor from the consumer towards CascoTotaal is the customer. The customer can be a housing association for the social housing sector or a housing developer for the private sector.

These customers are chosen because the production process of industrialised housing construction at CascoTotaal is currently only focused on larger volumes of houses being built per production run. Therefore, direct sales to the consumer is non-existent. For this reason, the customer and the consumer are always separate parties in the supply chain of industrialised housing construction at the moment.

For the construction of the house itself contractors need to be involved since CascoTotaal does not build houses themselves, the main contractor is the direct actor in between CascoTotaal and the customer responsible for the house during the finishing process. However, the main contractor also employs multiple specialized subcontractors to carry out the construction work of specialised modules such as the technical systems. Therefore, the main contractor and subcontractors are both included in the business scope diagram as stakeholders.

For CascoTotaal its internal processes, the stakeholders are three separate actors: Office, Structural works factory and Finishing factory. The office is the connection of CascoTotaal with the rest of the stakeholders and controls the other two actors (finishing and structural works factories) within CascoTotaal. The Structural works factory is the internal supplier of the concrete structural units needed for the production of the houses in the finishing factory. The third actor of the CascoTotaal is the finishing factory. CascoTotaal as mentioned earlier, does not assemble the houses themselves, but facilitates the finishing factory for the main-contractor and sub-contractors to perform the actual construction work.
Last in the business scope diagram are the suppliers of the industrialised housing construction process. These suppliers are both the suppliers of raw materials for the structural works factory and the module suppliers for the main- and sub-contractor(s) through the inventory of the Finishing factory. In order to keep the supply chain mapping easier to generalize to other industrial housing methods it is chosen to represent the suppliers per module instead of per product they supply. It can therefore be the case that multiple modules are supplied by the same physical supplier. Both the raw material suppliers and the module suppliers of the finishing factory are included as the first step in the business scope diagram. The supply side of the business scope diagram does not include an earlier level of supply since most raw materials for construction can be obtained from multiple sources.

6.2.2.b Flows in the business scope diagram

Within the business scope diagram three general flows are distinguished. The material or physical flow which includes al tangible assets needed for the construction of the house from suppliers until the final consumer. The physical flow is depicted in the business scope diagram as a solid line in Figure 23. The second flow in the business scope diagram is the flow of information or intangible assets depicted by the dashed line in Figure 23. In the business scope diagram the information flows are simplified representations, a more detailed analysis of the information flows will be made during the BPMN mapping later in the report. The third type of flow in Figure 23 is the manpower flow. Normally this is not a flow of a business scope diagram, but for this specific case it is an important flow and therefore depicted in the business scope diagram of CascoTotaal. The directions of all the three types are depicted in Figure 23 by the arrows.

Physical flow

The physical flow is a forward flow with two main starting locations at the suppliers of the raw materials for the structural works and module suppliers for the finishing work. The raw material physical flow starts at the suppliers of the structural works factory, this flow includes all the materials needed for the concrete structural work to be constructed. These suppliers combine into one stream through the structural works factory where they are transformed into the structural works module and continue to the finishing factory. The second physical flow starts at the module suppliers of the finishing factory, these flows from the suppliers combine together with the physical flow of the structural works factory through the finishing work factory. The finishing factory combines all the physical flows since it is the inventory for all the other manufacturing processes from now on. The end product of the finishing work factory are the units that make up the complete house, ready for transport to the final location. However, the Finishing factory does not build the houses themselves. The materials that the finishing factory holds as stock are used by the contractors. The main contractor is the party that is responsible for the build and therefore the physical flow now continues from the finishing factory to the main contractor. The main contractor is responsible for the constructing, transportation and placement of the house. After the placement of the house by the contractor, the physical flow continues to the customer who takes ownership after the placement. The physical flow takes one last step when the consumer receives the key of the house from the housing association or housing developer.

Information flow
The information flow starts with the exchange of information between the customer (housing association or housing developer) and the consumer. This information exchange is bidirectional and includes multiple instances of information exchange like contracts and housing specifications as requested by the consumer and customer. There is no direct information exchange between the consumer and the contractor in the current process. For this, the information flow continues between the customer and the main contractor. This is also a complex bidirectional information flow including contracts and housing specifications as discussed with the consumer and designed by the customer. The main contractor has a bidirectional information exchange with the sub-contractors about the sub-contracting jobs to be performed per house during the construction process and the contracts needed to guide these subcontracting jobs. Besides this the main contractor is also the main connection of the information flow between the customer and CascoTotaal with a bidirectional information exchange. However, this information flow is only with the office of CascoTotaal. The office will direct all the information flows within CascoTotaal and will have a single direction information stream with the suppliers about the ordering of materials of the structural works factory. The finishing factory also has a single direction information flow towards the suppliers of the finishing work to order the necessary materials according to the production planning and specifications of the houses to be constructed. Within CascoTotaal, the office has bidirectional information exchanges with both the structural works and finishing factory the guide the process within both factories and to collect information needed in order to discuss the construction requirements with the main contractor.

Manpower flow
The manpower flow is present in the business scope since CascoTotaal does not construct the house themselves. In the finishing factory facilitated to the contractors by CascoTotaal, the houses are built by the main contractor and sub-contractors. However, the physical flow and manpower flow do combine in the finishing factory. Therefore, external manpower is required from the main- and sub-contractors. For this reason, the manpower flow is depicted in the business scope diagram.

6.2.3 SCOR model
To build the final reference of the supply chain map for the current situation analysis, the SCOR model is chosen as the tool for the mapping as described in the case study design and protocol. As input for the SCOR model the business scope diagram is used as a general guideline for the limits of the supply chain mapping with the SCOR model.
The SCOR model for this case study at CascoTotaal is set up in two phases. The first phase will analyse the performance attributes of CascoTotaal. During the second phase, the supply chain itself is mapped following the SCOR methodology to create a thread diagram of the total supply chain. The mapping is constructed with the help of observations and interviews within CascoTotaal, its suppliers and customers as seen in Appendix I.

6.2.3.a Performance attributes

The SCOR model begins with extracting the performance attributes of CascoTotaal in order to find their strategic focus towards the industrialised housing construction market. The performance attributes are analysed following the case study protocol by using the SCOR model attributes: Reliability, Responsiveness, Agility, Costs and Assets (Supply Chain Counsil, 2015).

Reliability

The reliability attribute dictates the ability of a company or process to perform a certain task as expected. The more reliable a company or process, the more predictable the outcome will be. At CascoTotaal reliability is very important for the smooth running of the entire process. Because the finishing factory is divided in ten stations, each station has to finish their work that day in order to keep the process running smoothly. Also, the process has to deliver the right product for every unit since all the units are predefined for a certain customer before the production process is started. All of this combined means that reliability is very important to CascoTotaal and its process.

Responsiveness

Responsiveness dictates the speed at which tasks are performed and the ability to change the process is one of the key features of responsiveness. When compared to the traditional way of constructing houses the total time of construction has dramatically decreased. However, at the moment the production process of CascoTotaal focusses less on the total construction time decrease, but rather on making the process more efficient overall. Therefore, the attribute of responsiveness is twofold at CascoTotaal. It is important for the external customer who has to choose between the traditional building method or industrialised housing construction. However, for the internal process operations responsiveness is less important as a factor since the decrease in construction time is an attribute that is heavily reliant on other factors of the process.

Agility

Agility is the focus of a company to excel in the ability of their process to adapt to changing circumstances or external influences. At the moment CascoTotaal is not focussing on the agility of their process. The process is very depending on main- and sub-contractors to keep the process running. This dependency decreases the agility because if one of them goes out of business or has other priorities the whole process stops. Also, the number of suppliers for the materials is very limited. For example, the concrete needed in the production of the structural unit comes from one single supplier who also has limited suppliers. If in the production of the concrete one supplier cannot deliver the whole process stops. Therefore, agility should be a main focus point in order to excel the process to a higher level, but at the moment CascoTotaal is not focussed on agility.

Costs

The attribute costs include all the costs that are related to the running of the process. Examples are; labour costs, material costs, transportation costs, etc. For CascoTotaal costs are an important factor of their process and is one of the main focus points at the moment. Because CascoTotaal chose to build their industrialised houses from more durable materials such as concrete the production costs of the structural works are more expensive than other industrial houses. However, when purely looking at CascoTotaal themselves they have a huge direct advantage because they do not employ the workers themselves, they are all subcontracted. Therefore, these costs are not directly effecting CascoTotaal. However, these costs will be represented in the final product cost and the total costs of the supply chain. So, at the moment CascoTotaal is not cost leading in the market for industrialised housing construction but the costs attribute a main focus for the process.

Assets

The attribute of assets describes the efficiency of asset management. In other words, how efficient are the assets needed in the process be utilized. Because of the controlled production circumstances at CascoTotaal asset efficiency is very high. Production is always continuing and because the whole product is known beforehand most of the needed materials can be ordered in the exact needed quantities. Also, the inventories can be closely monitored since there is a set takt time and tight planning when certain products are needed. However, not all possibilities of tight asset management are currently utilized at CascoTotaal. This originates at the external parties that are responsible for the building process. Most of the parties still have a traditional building mentalities were asset management is far less important than in the industrial manufacturing or assembling process.

Combining all the different categories of performance attributes it can be concluded that Reliability and Responsiveness are the two main focus points of CascoTotaal. Agility is a weak point at the moment, and Costs and Asset Management require attention to be improved in order to take away disadvantages.

6.2.3.b Thread diagram

The mapping of the actual supply chain of CascoTotaal using the SCOR model is done with a thread diagram in two stages. First the execution processes are mapped. These can be compared to the physical flow of the business scope diagram. After the execution processes are the planning processes that regulate the execution processes are mapped.

Execution processes

Using the process categories and level 2 elements of the SCOR model, discussed in the case study design of this report, the physical processes of CascoTotaal are modelled in chronological process steps. To give a better overview of the entire supply chain the execution processes which incorporate the “Source”, “Make” and “Deliver” process categories are modelled for CascoTotaal in Appendix II. In the execution process thread diagram, the stakeholders of the business scope diagram are the input, however, to give a better representation on the supply side of CascoTotaal, the model is mapped in more detail by splitting the materials suppliers is first- and second tier suppliers.
By analysing the execution processes a highly-detailed view is created of the process steps involved at CascoTotaal. The Execution processes focus on the material flows within the supply chain and the movement of these materials through and by the different stakeholders. The execution process map also shows where the products are physically transformed by mapping the “Make” elements. In the mapping, this physical transformation is also categorised according to the level 2 elements in order to see how the change is organized.

When for example the kitchen supplier is analysed, it is seen that a kitchen is made from four elements on the component level. The cabinets and countertops are Made-to-Order according to the customer or consumer preferences. However, the appliances and sanitary fittings are Made-to-Stock products directly sourced from the second-tier supplier stock. The four elements needed for the kitchen are then combined at the kitchen supplier a Made-to-Order kitchen and delivered to the inventory of the Finishing factory. The sub-contractor or main-contractor who is responsible for assembly of the kitchen in the final unit sources the kitchen from the inventory and places it in the unit. The unit is therefore Made-to-Order by the contractor. Finally, when all the separate modules are assembled they are delivered to the customer who sources it and directly delivers it to the consumer who receives it.
A trace like this can be made for every separate product module stream in the final product (the house) from supplier to final consumer. These traces of the execution process will later be used to determine the Customer Order Decoupling Points of the current process. By examining the point in the chain where the components become consumer specific.

Planning processes
In this second phase of the thread diagram, the planning processes are added to the thread diagram (Appendix III). The planning process are a more detailed representation of the information flows as seen in the business scope diagram and are mapped by expanding the execution process map with the information streams needed in to perform the separate execution steps in chronological order. By analysing the separate planning elements, it is seen that every stakeholder plans their individual supply chain, but all supply chains are dependent on each other in order to ensure a constant physical flow. Therefore, coordination should be needed between the different stakeholders in order to coordinate the total supply chain. This is attempted in the process of CascoTotaal by forming a “bouwteam” that coordinates the supply chain planning with structured meetings at set points in time with key stakeholders of the process (visualised in the thread diagram as the green P1 arrow). At the moment, the “bouwteam” consists of three stakeholders: Customer, Main-contractor and CascoTotaal.

Customer
The customer (housing association or developer) is part of the “bouwteam” since they are the initiator of the whole process. Also, the voice of consumer is represented by the customer since this is key in the production process and the consumer has to approve the final house and live in it. While it is not possible to involve every consumer individually, the customer also represents the consumer since these two stakeholders have and independent bidirectional information flow as seen in the business scope diagram.

Main-contractor
The main-contractor is part of the “bouwteam” to coordinate the actual construction of the house and to communicate the building schedule and actual production status to the sub-contractors involved.

CascoTotaal
CascoTotaal is present since they are the facilitator of the finishing factory and the owner of the building concept. CascoTotaal is also the representative of the supply side of materials since they have to deliver the needed materials from their local stock in the finishing factory to the contractors and need to know the planning of the process and required materials.

Even though it seems like all the important stakeholders are represented in the "Bouwteam", it can be argued that the meetings are not sufficient to run the entire process smoothly. It is seen during the literature review that to smoothly run industrialised housing construction on a large scale, very close and daily supervision is needed. Even though the meetings of the "bouwteam" are structured meetings, they are not taking place daily in order to ensure a structured and smoothly running process. They are used to take away large bottlenecks for the process on the long term. It is therefore argued that the meetings of the "bouwteam" do contribute to the steering of process but are to infrequent to solve problems efficiently on a daily basis.

6.3 Process mapping

As seen in the planning process mapping of the SCOR model, there is a lot of information exchanged between the stakeholders of CascoTotaal its process. In order to get a more detailed view on the information exchanged between these different stakeholders and the needed information to ensure a smooth-running process, a process mapping is made using the Business Process Model and Notation (BPMN) as described in the case study protocol. For the process mapping, the business scope diagram will provide the actors to be mapped in the BPMN. The actors extracted from the business scope diagram are: Consumer, Customer, Main contractor, Sub-contractors and the three departments of CascoTotaal (Appendix IV). The material suppliers are left out of the BPMN since they are not part of the decision makers in the information stream but purely provide the requested materials as ordered by CascoTotaal. The BPMN was constructed using the same interviews as for the SCOR model as described in Appendix I together with internal observations and company documents.

Using the BPMN of CascoTotaal, the exact information flows corresponding to the material flows from the SCOR model can be extracted. It is seen that the starting point of the process has a twofold situation. There are two starting points needed to start the process of CascoTotaal. The first starting point is the intention of the customer (housing association or housing developer) to build a new house. If the customer does not have the intention to build a new house, there would be no construction request towards the construction companies for the fulfilment of this intention. However, there is a second starting point needed in order to start the process. This second starting point is that of the consumer who is looking for a new house and is willing to buy or rent a house from the customer. Only when these two information streams meet will the process be able to start for the rest of the stakeholders in the supply chain. In between the intention to build the house and the house being delivered to the consumers there are multiple information exchanges between all the stakeholders in the process.

When analysing these information exchanges between the different stakeholders, it is seen that all exchanges of information happen on the consecutive stakeholder level in the supply chain. For example, the sub-contractor only exchanges information with the main-contractor and the Housing association only exchanges information with the main-contractor and the consumer. No stakeholders are skipped in the supply chain. So, when information of the consumer is needed by the sub-contractor, this information has to pass through the customer and the main-contractor. This way of information exchange between stakeholders can be very time-consuming and inefficient when the stakeholder who needs to pass on the information does not need the information themselves.

In the flow of information, there is a point from where the preferences of the consumer are taken up in the exchanged information between stakeholders. In the current BPMN the point of entry for consumer preference is located at the consumer at the “choose options” step. The BPMN is now used to find the points where consumer choice is introduced at the various stakeholders and to find what role these stakeholders have in ensuring the consumer choice is represented in the final product. This is represented in Appendix IV by the blue shaded steps of the second BPMN model. These blue steps are subject to change if the preferences of the consumer or the product is changed based on consumer choice. The first blue shaded process step for each consumer is the CODP for that specific stakeholder. As can be seen in Appendix IV, the point of consumer involvement (CODP) moves further forward in the supply chain with every stakeholder.

From the BPMN model it can therefore be concluded that, when the starting points of the information flows are compared to the starting points of the physical flow it is seen that, the material flows all start at the suppliers while the information flow starts at the customer and consumer level. When the information flow from the BPMN and the flow effected by consumer choice are now compared it is seen that the flow of information runs downstream towards the supply side of the model until it meets the physical flow of products and then the two flows combine into one flow until ending at the consumer level. In order to find the change in the supply chain it is important to find the point where the physical flow and the information flow meet and where the order is linked to the preferences of the consumer. These points are defined in this research as the Customer Order Decoupling Points (CODP).

6.4 Customer order decoupling point mapping

For the mapping of the Customer Order Decoupling Points (CODPs) as part of the current situation analysis at CascoTotaal, the current process is used as mapped by the SCOR and BMPN model is used as the main input. At the moment, the mapping of the CODPs in the process of CascoTotaal is based on the CODPs from the customer perspective and not the perspective of the consumer. This is the case because CascoTotaal is marketing their products directly to the customer who is the decider of the output product at the moment. A current CODPs mapping focused on the current choice and the consumer its perspective is made in the future scenario creation later in this report. Here the possible CODPs for the product itself are mapped and therefore the customer perspective is used.

The mapping of the CODPs starts with the determining of the upper most level CODP. This upper level CODP is determined on the product level. The product in the case of CascoTotaal is the final house since this is what CascoTotaal is selling as a product to customers. Since the final house consists of multiple modules that can be adjusted on a component level by the customer, the final house is categorised as an Assembled-to-Order product or Customised standardisation. This categorisation of the house is the result of the variation possible in the assemblage of the modules however, not on the level where the modules are especially designed for every customer individually. Figure 24 shows the placement of the house in the CODP matrix as previously constructed from the model of (Barlow et al., 2003).

	Pure Standardisation	Segmented Standardisation	Customised Standardisation	Tailored Customisation	Pure Customisation
Product			HOUSE		
Product module			Interior layout Technical systems Interior finish	Kitchen Bathroom	Structural work Exterior finish

Figure 24: Upper level CODPs for CascoTotaal

The middle levels of the product, the product modules, are also mapped in Figure 24 showing the positioning of the separate modules with regards to the final product. It can be seen that even though the house is categorised as Customised standardisation, its product modules can be categorised completely different. The same is true for the lower level product components mapped from the product modules.

When analysing the middle level CODPs of the product modules, it becomes clear the there is great difference in the level of customer input for the different product modules. The results of the mapping show that; Interior layout, Technical systems and Interior finish are categorized as Customised standardisation. This means that these three modules are Assembled-to-order. The customer has some influence to customise these modules. However, all the needed components for this customisation are standardized products sourced from stock and fitted to the units as the customer required them. The products do have some form of variation, but the variation is limited to the components level. This can also be seen in the thread diagram of the SCOR model. All the needed components of the; Interior layout, Technical systems and Interior finish are sourced from stock components.

The modules Kitchen and Bathroom are categorized as Tailored customisation meaning that the modules follow a Made-to-order production strategy. Like the previous modules, this production strategy can also be seen in the SCOR thread diagram where the "Make" step is further backwards in the supply chain and is a Made-to-order step. Even though the modules offer more customisation possibilities, the components used in the modules are still some form of standardised products to choose from, the difference is that the components are not yet assembled into subassemblies and therefore, the choice in components can be left to the customer without impacting the sub-assembly process.

The last two modules are the Structural work and the Exterior finish. These two modules see the most input from the customer with regards to customisation and are categorised as Pure customisation or an Engineered-to-order production strategy. For the structural work this is clear as compared to the SCOR thread diagram since the "Make" process is also an engineered to order step in the model. The Structural work module is completely designed according to the customer specifications with free dimensioning in length, width and height. Also, the needed subcomponents are incorporated in the design of the Structural work and are placed in the module according to the customer preferences. However, for the Exterior finish this is not as obvious in the SCOR thread diagram. The reason for this is that, in the SCOR thread diagram the subcomponents are not Engineered-to-order and neither is the process of the exterior finish itself. However, because there is so much choice in exterior finish and the layout of the exterior finish is completely open to the customer, the module is still categorised as Pure customisation due to the large amount of possibilities even though the components used are mostly standardised products.

Now that the separate product modules are all categorised according to the level of customer influence, the modularisation is expanded one last time to the component level. For these lower level processes the components as defined in the modularisation section of this report will be used as inputs. The components will be categorised following the same method as the higher-level categorisation previously. However, the components will be grouped per product module in order to keep the mapping structured. The mapping of the components will form the basic input for the possibilities of customisation for the consumer later in this report during the construction of the future scenario.

Within the structural work (Figure 25), it is visible that the components are wide spread between fully standardised and pure customisation components. Starting with the mounting hardware needed for the casting, these are sourced from a local stock in the structural work factory of CascoTotaal and the customer has no say in the placement of this hardware since it is not a feature of the house, but needed for the production of the units. The concrete is also a Pure standardised product and sourced from the local concrete mill and no influence of the customer is present for the type of concrete to be used. However, the Installation materials are Segmented standardisation. The components needed for the technical installations in the structural work are all made-to-stock products sourced from a local stock. The customer has some say in the use of materials and the location of the materials within the structural work. Examples of these choices are, the decision to run floor heating or not or the placement of electrical outlets in the concrete walls. So, even though the sub-components used are purely standardised products the customer has a choice and therefore the component is Segmented standardisation. The last component is the rebar used to reinforce the concrete structure. Even though the rebar components as seen in the SCOR model are all stock products the rebar itself is engineered to the specific structural work being built for the customer. The customer has no choice, but all choices made in the structural work module and even other modules influence the rebar component. It is therefore engineered-to-order or Pure customisation.

	Pure Standardisation	Segmented Standardisation	Customised Standardisation	Tailored Customisation	Pure Customisation
Product			HOUSE		
Product module					Structural work
Component	Mounting hardware Concrete	Installation materials			Rebar

Figure 25: Lower level CODPs for Structural work

In the Interior layout (Figure 26), it is seen that even though the module itself is categorised as Customised Standardisation, the components; Gypsum board and Metal profiles are both Pure Standardisation components since the interior layout itself can be changed by the customer. But, the components used for the creation of the interior layout are all standard products sourced from a local stock at the finishing factory of CascoTotaal.

	Pure Standardisation	Segmented Standardisation	Customised Standardisation	Tailored Customisation	Pure Customisation
Product			HOUSE		
Product module			Interior Layout		
Component	Gypsum board Metal profiles				

Figure 26: Lower level CODPs for Interior layout

For Technical systems (Figure 27), the module itself is also categorised as Customised Standardisation. However, the Electric, Water and Ventilation components are all categorised as Pure Standardisation. They are not sourced from a local stock at the Finishing factory, but from a local stock at the reseller of technical systems. The components are all standardised components. However, no choice is offered in these components for the customer. In the Spero 1 single family home, the technical systems are all designed with a certain energy level in mind and the chosen energy level dictates the components used. A little choice is however offered to the customer for the Heating components where there is customer choice of heating methods. Therefore, heating is categorised as Segmented Standardisation where the components are still standardised products but, the configuration of the heating system can be changed to the preferences of the customer.

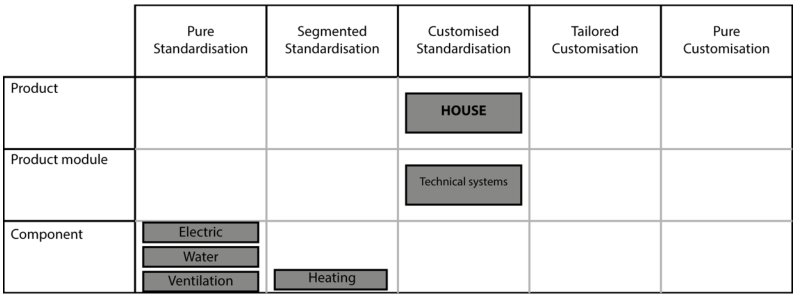

Figure 27: Lower level CODPs for Technical systems

For the Interior finish module, a comparable situation can be seen as for the Technical systems (Figure 28). The module itself is Customised standardisation due to the amount of choice offered to the customer. However, all the components are standardised products. Difference in categorisation for the Interior finish is based on where the products are sourced from and how they are sourced. The ceiling is always finished using materials sourced from a local stock and at the moment no choice is offered, therefore it is categorised as Pure Standardisation. The floor and interior walls can be finished differently following the preferences of the customer but, the materials are always standardised products sourced from a local supplier and therefore these are categorised as Segmented Standardisation.

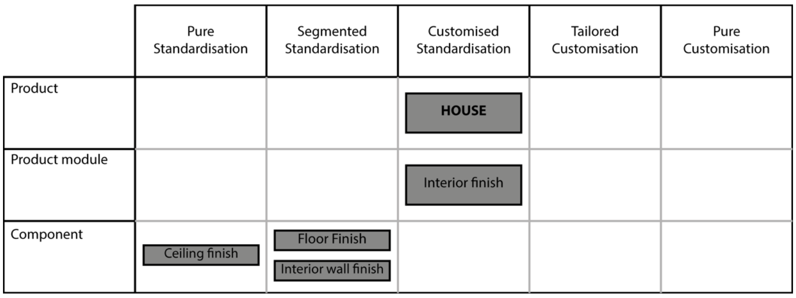

Figure 28: Lower level CODPs for Interior finish

When decomposing the different components of the Pure Customisation Exterior finish module (Figure 29), it becomes clear the for the Exterior finish the components are categorised in two categories. The first category is the Segmented Standardisation in which the Insulation and the Exterior roof finish are categorised. For the insulation, it is categorised as Segmented standardisation for two reasons. The first is that the products are sourced from a central stock at the supplier. The second is that the customer does have some choice in the insulation to be used and especially the insulation value (thickness) to be used

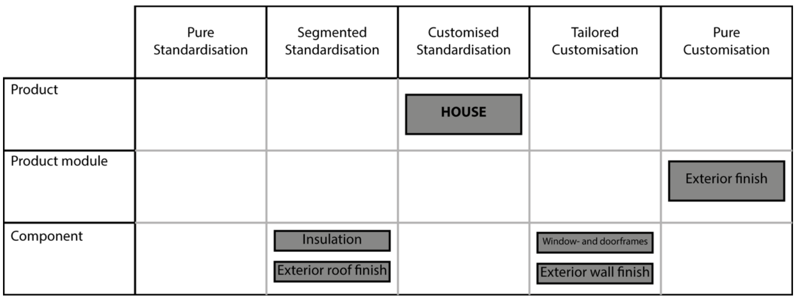

Figure 29: Lower level CODPs for Exterior finish

in the module and final product. For the exterior roof finish the customer can have choice in the type of finish to be used but, the materials that make up the components are all sourced from large stocks at the supplier. Therefore, it is Segmented Standardisation since there is choice on the component level, but the components themselves are standardised products. The second category of the Exterior finish is Tailored customisation. Within this category, the Window- and doorframes and the Exterior wall finish are placed. Both of these products have some form of standardisation in them with regards to the dimensions and choice options as set by the suppliers. However, they are not produced until the customer has made a choice from a wide verity of options. The products are then produced according to the specifications chosen by the customer. Therefore, these two components are categorized as Tailored Customisation since there is a lot of choice in these two components but, the components are not designed for the specific customer.

As seen in the SCOR model, all product modules until now do not have any “Make” processes within the module suppliers themselves. The modules are dependent on the “Make” processes before and after the product module to determine their categorisation. For the Kitchen and Bathroom modules this is different. The Kitchen and Bathroom are preassembled at a different factory and then transported towards the finishing factory of CascoTotaal. The impact of this different way of production is analysed next for the component level of the Kitchen (Figure 30) and Bathroom (Figure 31) modules.

For the kitchen module, it is seen that the Appliances are all sourced from local stocks. These local stocks however, are located at the distributers of the appliances. There is choice in appliances for the customer, however the appliances themselves are pure standardised products and cannot be changed themselves in any way. For the tiling, the products (tiles) are pure standardisation products but, since the tiles can be mixed and matched by the customer the component Tiling will have a segmented standardisation categorisation. For the cabinets and the counter tops a different approach is used by the kitchen manufacturer. Because there is so much choice in cabinets these products are made-to-order from a standardised choice set once the preferences of the customer are known. The same is true for the counter tops and therefore, the cabinets and countertops are categorised as Tailored Customisation.

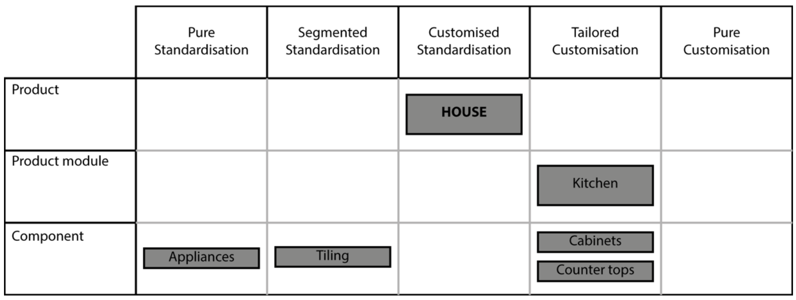

Figure 30: Lower level CODPs for Kitchen

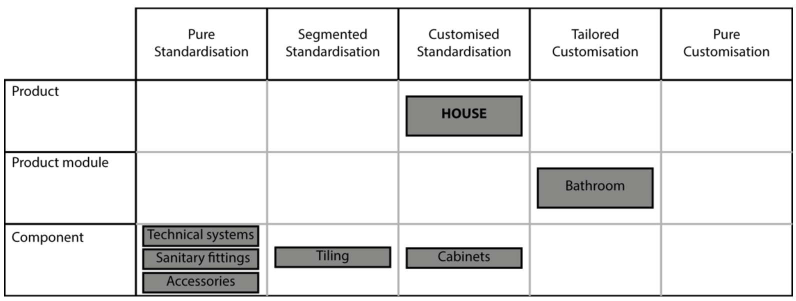

Figure 31: Lower level CODPs for Bathroom

For the Bathroom, even though the product module has the same categorisation as the Kitchen it is seen that the components are organised differently. In the bathroom, most of the components are categorised as Pure Standardisation. It is seen on the module level that there is a lot of choice in a bathroom, but the components that are used to construct the bathroom are mostly stocked at local resellers or sourced from a local stock at the finishing factory. This is true for the Technical systems used in the bathroom, the Sanitary fittings and the Accessories. However, the Tiling is categorised different like it is in the kitchen. This is because even though the tiles are standardised products, they can be mixed and matched to the preferences of the customer. The cabinets of the bathroom allow for less customisation as the cabinets of the kitchen. Therefore, the cabinets of the bathroom are not Made-to-order but, Assembled-to-order since the components needed for the cabinets are standardised and not made for that one customer but put together from a selection of standardised components, categorising them as Customised Standardisation.

With the lower level component mapping of the CODPs complete, it can be seen that on the lower level of the CODPs mapping it becomes even more evident that even though a higher level has one categorisation, the lower level components can have totally different categorisations. For this research, the categorisations per product module will be used and the lower level component categorisations will later be used to find the possibilities for customisation and the influence on the supply chain since for example customisation can be achieved with standardised parts on some modules while other modules require custom made parts in order to be able to involve customer choice.

6.5 External effects mapping

During the case study, expert interviews were held with stakeholders throughout the supply chain (Appendix I) in order to find a preliminary categorisation of the external effects. However, during the interviews and company observations it became clear that there is hardly any data measured or information collected about the performance of the process with regards to the external effects categories determined in the case study protocol. The categories of external effects from the case study protocol were therefore used as a guideline for a preliminary mapping of the current external effects of CascoTotaal. Later in the comparison of the current and future situation, these preliminary results will be the input for the effect matrix and recommendations for measurements to be put in place in the process of CascoTotaal. A description of the effects per category is given in this section. At the end of this section and a summarising table is created with all the discussed effects per category (Table 8).

6.5.1 Construction time

With regards to total construction time of the house, the way of housing construction at CascoTotaal will have a large impact compared to the traditional way of housing construction. The total construction time of both combined factories at CascoTotaal can be as little as 12 days from nothing until the placement of the house at the final location. Within 2 weeks a completely liveable house will be build. However, due to this decrease in total construction time, problems in the surrounding processes may be expected. An example of this is if the building permit is delayed once the construction process has started at the factory. Because multiple processes on-site as well as at the factory (off-site) are running simultaneous (parallel) instead of after each other (linear), a small delay in one of the sub-processes will have very large effects on the total construction. Besides this, since the scheduled takt time per unit is one day, there is no time to rework mistakes in the construction process without having a negative effect on the total construction time.

A positive effect of the factory process is that due to the construction being fully indoors and conditioned, it is not influenced by the weather. Therefore, the chance of outside disturbances due to weather influences is minimalised and ensures the process can keep running whatever the weather.

6.5.2 Construction cost

Because CascoTotaal chose to manufacture their structural work from concrete, the production costs of the structural works are higher as competing industrial housing construction methods using wood- or steel framing. However, because concrete is more durable, these costs can be spread out over a longer total lifespan. This means that the initial purchase price of the house will be higher but, the lifespan over which to spread out these costs will be longer, so the annual costs of ownership will be the same or even lower.
A second costs factor is the time it takes to construct the house. Because the total construction time is lower as in traditional housing construction (seen in the previous section), the labour cost of the workers represented in the purchase price of the house will be lower as would be in traditional housing construction methods. However, because the final oversized heavy units will have to be transported over the public roads, the transportation costs will include an extra factor. For the rest of the materials used in the construction, the same amount of materials is needed as in traditional housing construction so the costs of materials will be the same. However, because the scale of production at CascoTotaal is in multitudes, the materials can be purchased in larger quantities which will have a positive effect on the total construction costs per house.

6.5.3 Quality

From interviews, it is seen that the different contractors active in the construction process of CascoTotaal noted a decrease in failure cost. This reduction was mostly accounted for by the repeating character of the work which over time caused the amount of rework to decrease for every unit. This rework decrease is an indication that the quality of the work is increasing. However, when rework has to be done, due to the time constraints as mentioned earlier, there is little to no room for rework without upsetting the entire process.
An effect to quality of the construction all taking place indoors where the climate is controlled and constant is that quality of the component used is not effected by the weather and curing times are very predictable. Therefore, the application of glue and sealant is controlled and the strength and finish is optimized. There is also little to no moisture in the houses once they are sealed. However, in order to guarantee the smooth running of the process and a constant increase in quality, closer monitoring of the process is required as in traditional housing construction. Things that cannot be done today cannot wait until tomorrow because tomorrow the unit is at the next station on the production line. Therefore, close monitoring of the process is required and faults have to be taken away as soon as possible.

6.5.4 Safety

First of all, the method of construction at CascoTotaal reduces the safety risk for the construction workers since they are not exposed to the weather. Weather exposure can for example make scaffolding slippery when raining. Also, there is almost no work at heights and the movement of large objects and machinery for the transportation of goods is reduced to a minimum while all the needed materials are right next to the production line where they are needed every day in the same location. Another decreased safety risk is that there are almost

no water and electricity lines running through the construction site because all needed facilities are worked away inside the finishing factory, this reduces tripping or electrocution hazards. The increased overview of the finishing factory with separate workstations also reduces the number of simultaneous work in confined space.
However, besides the safety effects on the workers, there are also safety risks for the people who live around the traditional construction site. This traffic created by a constant stream of construction materials being delivered and contractors arriving and leaving every day is relocated towards the facility of CascoTotaal, where it is fully controlled and out of harm's way. However, the transportation of the final units towards the final construction site is a large impact on safety for the surrounding area since these units are oversized and require special transport through sometimes narrow suburban streets.

6.5.5 Environment

The environmental impact of industrialised housing construction at CascoTotaal is twofold. At the one hand, it is less polluting to the environment since the repetition in the work leads to less material waste. Also, the waste that is created is confined to the factory and can be disposed in a more environmental friendly way. With waste management and the construction taking place fully indoors the risk of construction materials or spillage entering into the ground at the construction site are reduced and the use of water and spillage of water due to leaks in the water system are reduced to a minimum. However, because everything is done in a controlled factory there is an increase in the environmental impact. The factory will consume more energy as a traditional construction site because of heating and air extraction equipment. Also, the factory needs to be lighted electrically throughout the day instead of only at night. Also, the transportation of the large units will have an environmental impact.

A summary of all the discussed external effects is given in Table 8. Here it can be clearly seen that even though the process of industrialised housing construction has a lot of advantages, there are also negative effects to overcome.

Table 8: External effects summary

Construction time	Construction costs	Quality	Safety	Environment
Positive Decrease in construction time (12 days) Less disturbances that cause delays **Negative** Decreased time for rework options Increased dependency on external processes	**Positive** Life span increase compared to other industrial methods Decrease in man-hours per house Larger material volumes overall **Negative** Concrete construction Increase in transportation costs	**Positive** Decrease in number of faults Decrease in moisture levels More stable curing times due to climate **Negative** Decreased time for rework before delivery	**Positive** No weather influences Less falling hazards Less tripping hazards Less heavy machinery Less simultaneous work in confined spaces Less traffic to and from final construction site **Negative** Heavy subassemblies used in construction process Heavy transport in suburban area of final units	**Positive** Less material waste Easy waste disposal Less risk of ground pollution on construction site **Negative** More electricity use (factory lighting, heating, air extraction) Heavy transport of final units

6.6 Conclusions current situation analysis

From the current situation analysis, multiple conclusions can be draw regarding: The current production process, the performance of this process and the external effects at CascoTotaal. Starting at the modularisation for CascoTotaal its the Spero 1 single family home, it was seen that the modularisation as defined in the case study protocol is a good fit. The product was chosen as is a base situation from a range of products CascoTotaal offers since this product is the most asked for by the customers of CascoTotaal. During the modularisation, the higher-level components were decomposed with the help of interviews held within the supply chain of CascoTotaal and company documents describing the Spero 1 product.

Using the modularisation as an input, the basic supply chain model of CascoTotaal was created and it was seen that the finishing factory does not perform any work besides functioning as a warehouse for the components needed by the contractors, all the actual finishing work is done by external contractors. By comparing the basic supply chain model to the business scope diagram this becomes even more clear with the materials flow through the finishing factory while the main contractor and subcontractors provide the workforce. However, when analysing the information flow it is seen that the main contractor is the connecting party between: the customer (housing association or developer), the subcontractors and CascoTotaal. Also, it is seen that the external inflow of information at CascoTotaal takes place only through the office. This system of information flows can have a large impact on the process if these flows of information are not managed correctly.

By analysing CascoTotaal their performance attributes it becomes even more clear why these flows need to be coordinated in a structured way. The main attributes that CascoTotaal is focussing on are; reliability and responsiveness. Since reliability dictates the ability to perform a certain task as expected, the performance of the separate contractors in the finishing factory dictates the reliability of CascoTotaal. This is even more visible for responsiveness, which dictates the speed at which a task is performed. The current speed of the process is controlled by the takt time, set to one day at the moment, this means that every day the units move to the next station in the finishing factory. An opportunity for CascoTotaal is the attribute of agility, dictating the ability to adapt to changing circumstances. At the moment, the agility of the process is not very strong since sub-contractors perform their own task and there is a limited number of materials suppliers. In order to improve the agility and the rest of the process the connections between all the stakeholders therefore needs to improve.

By analysing the thread diagram of the SCOR model, the weak points in the performance attributes and the supply chain become more visible. It is seen that all the material flows converge at the contractors, the planning processes within the thread diagram also show that every stakeholder is responsible for their own supply chain planning. However, the weak points of the process as discussed earlier with regards to coordination of the information flows is also seen in the thread diagram. The three main stakeholders: Customer, Contractor and CascoTotaal are represented in an information sharing and process coordinating "bouwteam". This "bouwteam" has regular meetings to coordinate the process of construction with inputs from the most essential stakeholders. However, it is argued that these meetings are to infrequent in order to smoothly run the process on a daily basis since the total construction time is shortened drastically and tighter process control is required.

The SCOR thread diagram is also used in order to find the current flow of materials and how these materials are sourced. For the finishing factory, all the materials needed are sourced by the finishing factory and stored in a local stock until needed. Most of these materials are made-to-stock or made-to-order products, the only engineered-to-order product in the current process is the structural work. This information will later be used together with the information flows to find the Customer Order Decoupling Points (CODPs) per product module. These information flows are mapped in the BPMN diagram. From the BPMN it becomes clear that there are a lot of information exchanges needed in the current situation between the different stakeholders. By visualising the steps in the model that are depended on consumer preferences is becomes visible that even though the preference is expressed relatively late in the process of the consumer, the more towards the actual product the information flows, the earlier the consumer choice information is needed by the different stakeholder. By comparing this consumer information flow to the physical flow, the CODPs can be extracted.

The CODPs are categorised as one of five levels of customisation and mapped on three different levels. The more customised a product is, the earlier in the process the CODPs should be placed. The highest-level mapping is product level or house. This is categorised as a Customised Standardisation product, where there are some choices in the product. However, all these choices are from a standardised set of subassemblies. For the second level the house is split up into the separate modules as subassemblies. It is seen that the level of customisation for the modules is on more customisable side with higher levels of customisation possible. In order to determine the effect of this on the supply chain, the CODPs are also mapped on the component level. Here it becomes visible that even though the level of customisation on the module level is high, most of the options for the customer still consist of standardised components. With this information, the possibilities for future customisation features offered to the consumer can be created during the future scenario creation.

The final analysis of the current situation is the determining of the external effects for CascoTotaal in the five predefined external effects categories: Construction time, Construction cost, Quality, Safety and Environment. However, due to the limited amount of information collected by CascoTotaal about their process in the current situation, the determining of the external effects is a preliminary analysis in order to determine the main sub-categories of the five main external effects categories. This will later be used in the effects analysis to determine the external effects difference between the current and future situation. However, there is a correlation noted between the external effects. An example of this is the positive effect of construction time decrease which has a negative effect on quality since there is less time to correct mistakes. There is also a correlation specific for industrialised housing construction at CascoTotaal, when the positive effects are compared to the negative effects on the environment. Due to the concrete construction, the product has a longer life span but, the units are less safe to transport and the transportation has a larger impact on the environment. Also, the construction work taking place indoors has multiple positive effects on the construction time, the cost and safety. However, the factory has to be facilitated with heating and air extraction which will have a negative impact on the environment. Therefore, the effects cannot be seen separately and are always combined with the production method and other effects. This will have to be taken into account when the external effects are mapped for the impact of consumer choice later in this research.

7 Future scenario creation for CascoTotaal

The second stage in the case study is the creation of a future scenario based on consumer preference (Figure 32). This future scenario will be generated according to the case study protocol as discussed in the case study design and the measurements of consumer preferences will be based on (Hofman et al., 2006).

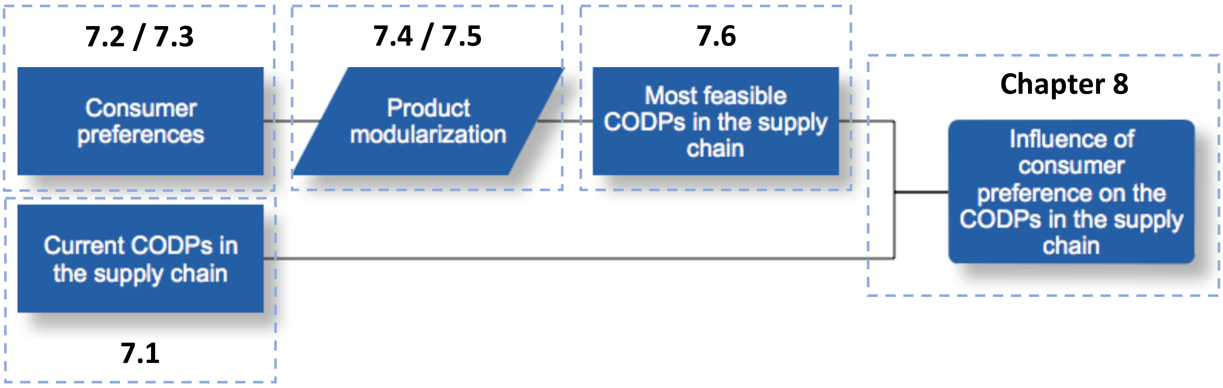

Figure 32: Chapter 7 Future scenario creation for CascoTotaal

For the creation of the future scenario, the consumer's perspective of the CODPs is the starting point. Until now, the customer's perspective has been leading in the mapping of the CODPs. In order to start the future scenario generation, the CODPs in the current situation as perceived by the consumer are first compared to the CODPs as found for the customer. With the formulation of the consumer perspective of the CODPs, the answer to sub-question 2 is finalised. In order to adjust the future scenario for the preferences of the consumers, these preferences need to be calculated for the different product modules as active in the process of CascoTotaal. If the measured preferences of the consumers with regards to customisation are projected on the current product modules the most feasible placement of the CODPs can be created by combining the preferences of the consumers to the current product modules of CascoTotaal. However, the preference of the consumer is not always feasible for the production process, therefor the limiting factors; logistical, technological and process limitations are incorporated and a trade-off between standardisation and customisation is made. The result of this is the final most feasible CODPs map based on consumer preference.

7.1 Current CODPs from a consumer perspective

During the current situation analysis, the CODPs were analysed from the customer (housing association or developer) perspective. In the current process, the customer decides what and to what extend is customisable for the product. Therefore, the total capabilities of customisability for the final product are not represented from the consumer perspective. In order to find the current CODPs and the current possibilities for consumer influence, the CODPs are remapped for the perspective of the consumer (Figure 33)

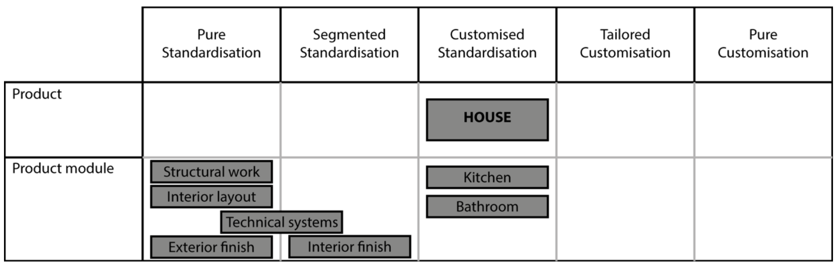

Figure 33: CODPs from the consumer's perspective

By comparing the CODPs on the level of the product module between the customer and consumer perspective (Figure 34) it can be seen that the possibilities for choice in the final product are not directly translated from the customer towards the consumer. It can be concluded that in the current process the possibilities for choice of the consumer are not fully exploited. The modules will now be analysed separately in order to find the current possibilities for consumer choice per module.

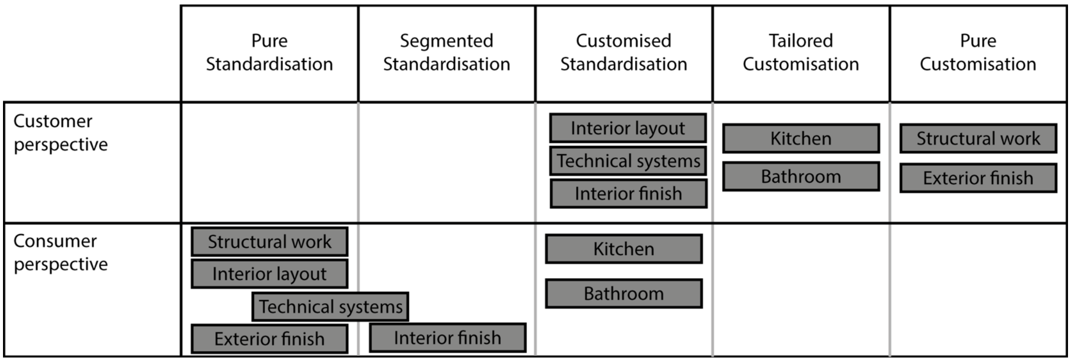

Figure 34: CODPs perspective comparison

Structural work

By comparing the CODPs between the customer and the consumer it can be seen that for the customer the structural work is completely open for change with a Pure customisation classification. However, the customer at the moment decided to not transfer this option towards the consumer. In the current process, the customer decides on the dimensions of every house and the consumer does not have any influence in this. Therefore, the CODP for the consumer is positioned as a Pure standardisation product that is bought from the stock of the local housing supplier.

Interior layout

For the interior layout, it can also be seen that the customer has more choice as is transferred towards the consumer. The customer decides on the floorplan and the positioning of the interior walls, the customer thereby standardises the interior layout from the perspective of the consumer. So even though the process can offer choice in the interior layout, this choice is not made by the consumer. The interior layout is now a Pure standardised module from the consumer's perspective.

Technical systems

For the technical systems, there is also a shift noted in the CODPs when comparing the customer's perspective to the consumer's perspective. For the technical systems, the customer does dictate the electrical system and the ventilation system. However, in the heating system there is choice for the consumer between radiator and floor heating using a traditional system or an electric infrared heating system. For the electrical system, there is also the option for the consumer to incorporate solar panels or not. However, these options are very limited when compared to the total amount of possibilities. A lot of choices are made for the consumer by the customer and only a couple of simple choices are offered to the consumer. Therefore, the CODP as perceived by the consumer is a mix of Pure- and Segmented Standardisation.

Interior finish
For the interior finish, there is also a difference in CODP between the customer and the consumer. The customer can choose different options for the finishing of the walls, the ceiling and the floors. However, in the current process of CascoTotaal, the consumer only has a couple of options. The only options that the customer translates to the consumer are the option for the walls to be stucco finished or not. The ceiling finish is determined by the customer and the decision to not finish the floors is also made by the customer. Therefore, the translation of CODP from customer to consumer results in a perceived CODP of segmented standardisation.

Exterior finish
For the exterior finish, there is the same shift in CODP visible as is for the structural work. For the customer, the exterior finish is a Pure customisation module since there are a lot of components that can be chosen. However, in the current product of CascoTotaal all these components are chosen by the customer before the house is offered to the consumer. Therefore, the consumer does not have any influence in the exterior finish and can only buy the house with the chosen exterior finish of the customer. The consumer therefore perceives the exterior finish as a Pure Standardisation module.

Kitchen
The kitchen module is one of the two modules that have relatively more customisability for the consumer. However, the consumer does not perceive the full possibilities of customisation. The customer choses a subset of options that are then offered to the consumer. In the current process the consumer has influence on the tiling in the kitchen, the countertops and the cabinet finishes. However, the design and location of the kitchen are determined by the customer. Also, the consumer can only choose from a predefined set of options that the customer wants the consumer to choose from. Therefore, even though the consumer has influence on the kitchen module, it is only perceived as Customised Standardisation since the kitchen is assembled from predefined parts and is not made exactly to the order of the consumer.

Bathroom
Besides the kitchen, the bathroom is the second module where the consumer has a relatively high level of influence. The consumer influence in the bathroom module can be compared to the consumer influence of the kitchen module where there is a predefined set of options decided by the customer for the consumer to choose from. This predefined set of options does not spread throughout all the components. For the bathroom, the components that the consumer can influence in the current product are; the tiling (where the consumer can choose from a by the customer defined limited set of tiles), there is also the possibility to choose from different subsets of sanitary fittings. All the other components are chosen by the customer. Therefore, the perceived level of customisation by the customer is limited to Customised Standardisation. The consumer can choose from a limited set of components that are then assembled to order. The rest of the components are not chosen by the consumer but by the customer.

7.2 Limitations for consumer choice at CascoTotaal

As seen previously, in the current process of CascoTotaal there can be a significant difference in the CODPs positioning based on the possibilities of the process and the translation of the CODPs towards the consumer by the customer. Since in the current situation these limitations of consumer involvement are a choice made by the customer. For this research, the true possibilities of consumer choice are researched. In order to find the most feasible future scenario for consumer choice, the possibilities and limitations per module with regards to consumer choice are first analysed in order to clarify the shift in CODPs between customer and consumer in the current situation.

The limitations are not mapped according to the current choice of options at CascoTotaal but are mapped according to technical, logistical or process limitations present in the production process of CascoTotaal. However, the possibilities are all projected on the Spero 1 single family home in order to keep them structured to a single product.

7.2.1 Structural work

For the structural work the consumer does not have a choice on the component level since these are determined by the engineering department of CascoTotaal. However, on a higher level there is the possibility to give the consumer choice in the dimensions of the house. These dimensions can be translated to the dimensions of the structural work of CascoTotaal. For the structural work, there are technical limitations to the concrete castings and there are limitations to the outbound transportation of the final units since the castings are the main part of the final units.

Technical limitations

For the technical limitations of the structural work the inner dimensions of the concrete castings are the most limiting factors. Due to the casting method, there are minimum and maximum dimensions for the structural modules. The maximum internal dimensions of the concrete castings are: 6000 mm wide, 9880 mm long and 3100 mm high. However, for the width and height there are also minimum dimensions that can be achieved with the casting method of CascoTotaal. The minimum internal width is 3000 mm stepping down from the maximum width in steps of 250 mm. The minimum internal height is 2400 mm being reduced in steps of 100 mm. However, the most important technical limitation for every concrete casting is the maximal weight of 23T.

Logistical limitations

Since the outbound logistics of CascoTotaal require the structural units to be transported over public roads, there are also logistical limitations to the structural work. These have to be taken into account by the engineering department of CascoTotaal when options are incorporated in the process. The maximum external dimensions of the finished housing sections that can be transported over public roads are; 4,3m wide during the day and 5m wide during nightly transports, 10m long and 3,6m high (including 500mm of foundation work). Both length and width include the exterior finish. The logistical maximum weight of the units to be transported over public roads is limited to 30T including all the other finishing work performed during the process as part of other modules added to the structural work.

By combining the structural work limitations and projecting these on the Spero 1 single family home, the possibilities of consumer choice in the structural work with regards to the dimensions can be seen. Since the Spero 1 consist of two structural unit sections connected to each other on the long side, the maximum external dimensions of the house are 10m long and between 8,6m and 10m wide including the exterior finish (limited by the logistical limitations). The minimum dimensions have no limitations for the length of the house, however, the interior width will have a minimum of 6m limited by the technical limitations. The maximum interior ceiling height of the house is now 3m limited by the logistical limitations and the minimum ceiling height is 2,4m limited by the technical limitations. The last limiting factor is the total transportable weight of the completed units after the finishing work at the factory. The maximum transportable weight as seen in the logistical limitations is 30T per unit, so a maximum of 60T for the completed house excluding the roof sections which are transported to the final construction site separately.

Besides the technical and logistical limitations, the construction of the structural work module also has some process limitations. For every change in dimensions the casting has to be adjusted before the rest of the preparation work can start on the structural work units, this adjustment of the casting is very labour intensive and time consuming. Therefore, changes in dimensions are only feasible if multiple units consisting of the same dimensions can be produced in a batch structure in order to keep the dimensional changes per produced unit to a minimum.

7.2.2 Interior layout

For the Spero 1 single family home the interior layout is constructed lightweight metal stud walls. These do not limit the choice of interior layout for the consumer in any way since they can be placed anywhere inside the structural work. The logistical limitations are also non-existent since the components of the interior layout; the metal stud profiles and gypsum board are both stocked and standardised products.
Since the components of the interior layout are used for the finishing of the interior within the structural work unit they are transported as part of the structural work to the final location. However, the weight of the interior layout has to be added to the structural work and together with all the other modules fitted to the structural work has to stay below the maximum of 30T as seen for the limitations of the structural work.
For the inbound logistics only the order quantity of the stocked products is impacted. However, there is a technical limitation to the freedom of the interior layout choices by the consumer. Since the bottom floor of the Spero 1 house is constructed using two concrete structural modules there is one interior wall in the layout highlighted in Figure 35 that has a fixed position. This wall cannot be changed since it is constructed from the concrete walls of the two structural units that are put together in order to form the structural part of the house. Apart from the highlighted interior walls on the floorplan the interior layout can be completely chosen by the consumer if preferred.

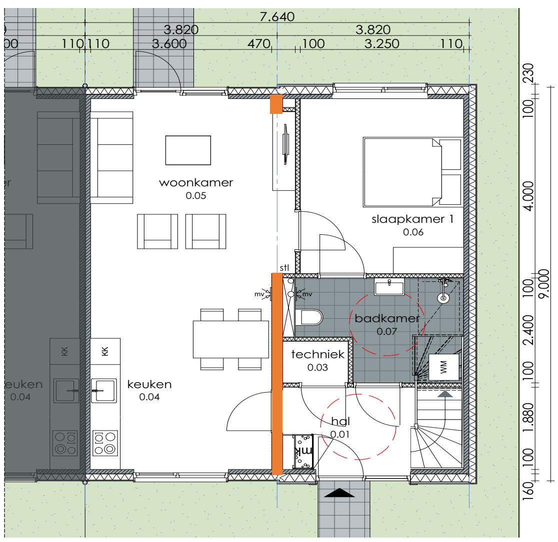

Figure 35: Spero 1 floorplan example

7.2.3 Technical systems

For the technical system, there are multiple possibilities for the consumer to choose from on the component level. When the components as defined previously for the technical systems are analysed based on interviews with the current technical systems sub-contractor working in the finishing factory of CascoTotaal, there are multiple options possible for all the components.

There are some technical limitations on the component level that are impacting the technical systems possibilities. One of the largest technical limitations is the combining of different parts, these parts all have to fit together. Even though the fittings of components are mostly standardised for the technical systems, the components have to be able to work together. An example of this can be seen in the combining of the space heating and warm water supply. If the chosen boiler is a combined model of space heating through radiators and also provides hot water to the water taps, the capacity of the boiler should have proficient power to perform both tasks without interruption.

It is therefore undesirable to let the consumer choose all the components individually since most consumers do not have sufficient knowledge to choose the right components needed in the technical systems. It is feasible to let the layout of the systems or the type of system to be used be chosen by the consumer, but the components should not be selected by the consumer.

Nevertheless, offering choices for the technical systems will have an impact on the inbound logistics of the process. If the choice of the type of systems or the layout of the components in the technical systems is left up to the consumer, the number of material suppliers will probably grow. These material suppliers will all have to be coordinated so that the right products arrive at the right time and are installed in the right unit according to the consumer's choice.

Besides the technical and logistical implications, offering choice directly to the consumer will also have an impact on the process itself. Because the installations are not only performed in a separate module but also in other modules such as the structural work. When changes apply to the technical systems that are placed inside the structural work these changes have to be known further in advance (before the construction of the structural work) and the per house drawings have to be adapted by the engineering department of CascoTotaal. An example of this could be the addition of floor heating or the positioning of electrical piping in the concrete walls because of wall outlet positions.

7.2.4 Interior finish

For the interior finish possibilities, there are no technical limitations with regards to the components used for the finishing of the structural works its interior. Technically every finish can be applied to the walls, floor and ceiling of the interior. However, because everything is possible as a material to finish the interior there is the risk of a large impact on the logistics of the process. The outbound logistics are not limited, but the inbound side of the logistics can be heavily impacted by the interior finish if choice options are offered to the consumers directly.

It is seen in the current situation analysis that the offering of choice for the interior finish is limited by the customers at the moment. The customer who builds the house offer limited choice options to the consumers in order to keep the process structured and manageable. If the choice of interior finish is completely left to the consumer it will have an impact on multiple aspects of the inbound logistics. At the moment, the consumer is free to finish the

walls and floor according to their liking, but it is not done during the production process at CascoTotaal. The interior finishing performed at the factory at the moment is minimal and the consumer is responsible for the finishing once the house is handed over to them.
The impact on the process of CascoTotaal when the finishing is performed at the factory will be that, first there will be a lot of separate material suppliers who all deliver materials to the finishing factory of CascoTotaal to be applied by sub-contractors. Different interior finishes will also require different sub-contractors to perform the specialised finishing jobs. An example could be when there is tiling in one room and stucco in the next room. This will have great impact on the inbound supply chain of materials. However, it will also have great effect on the coordination and information systems. All the materials needed for the process have different ordering times with their separate suppliers and the right materials need to come together at the right time for the application in the right unit. Therefore, the coordination of the process will be impacted greatly. Also, the applications of different materials can have a significant effect on the whole process since different materials have different application procedures and times. For example, tiling has a drying time and extra application steps in the form of the grouting. While these steps are performed on a floor finish no other work can be performed in that room.

7.2.5 Exterior finish

Besides the interior finish there is also the module of exterior finish. Like the interior finish, the exterior finish also has a lot of possibilities to choose from for the consumer, and like the interior finish these options have similar effects on the logistics and the process itself. However, opposite to the interior finish, the exterior finish does have technical limitations for the final product. The exterior finish includes the insulation of the house by using an exterior insulation method. In order to achieve a predefined energy efficiency norm, the thickness of the insulation will have to be added to the dimensions of structural work. Depending on the final position of the house (corner, build in or free standing) this will have influence on width and/or length of the house. The insulation is places on the outside of the structural work and can be finished in multiple ways. However, as seen in the logistical limitations of the structural work, the total outside dimensions are limited by the maximum transportable dimensions per unit, and therefore the inner dimensions will be impacted if a higher insulation value is needed (thicker insulation material). Besides this there are also specific impacts to the logistics of the exterior finish if consumer choice is incorporated in the module.
First, if the choice of finishing material is offered, there will be multiple material streams from multiple suppliers that have to be coordinated in the inbound side of the logistics. Also, multiple specialised sub-contractors will have to be used in order to place the exterior finish components on the structural units. The different materials will also require the process to be more flexible in time since different exterior finishes require different processing steps. Brik slips for example first need to be placed and then grouted a day later. When an artificial wood finish is chosen, the panels are placed on the insulation and no further steps are required. A last impact on the inbound logistics came forward during an interview with the current exterior finish supplier. At the moment, the different colours of brick slips are made to order at the factory and therefore, if choice in colour of bricks is offered a longer lead time for the ordering is required. The lead times on the inbound supply side can be impacted if choice is offered and better coordination between the supplier and the processor is required.

7.2.6 Kitchen

Since the kitchen module is produced at the kitchen supplier and transported as subassemblies to the finishing factory where it is put together and installed in the structural unit, the possibilities for consumer influence are dependent on the specific kitchen supplier. From interviews with the current kitchen supplier it has become clear that there are multiple possibilities for consumer influence and that according to the consumers budget the whole kitchen can be adopted to their likings. However, the kitchen supplier did mention that the more options there are to change in the kitchen the earlier in the process these options will have to be known. The reason for this being that, facilities in the structural module will have to be adapted to the kitchen. In contrast to the modules seen before, the inbound logistics of the finishing factory are not impacted by consumer choice. However, the inbound logistics of the kitchen supplier are impacted if more choice is offered since there are multiple made-to-order products in the kitchen. The more made-to-order products are introduced in the kitchen the longer the lead time will be for the total process.
A final remark will be the process impact of offering consumer choice in the kitchen module. Since the kitchen is depended on other modules such as technical systems and structural work, these modules can also be impacted when changes are made in the kitchen design. For example, if the position of the outlets in the concrete walls is changed, this will impact the structural work. Also, the technical systems will be impacted since these outlets will have to be connected to the rest of the system.

7.2.7 Bathroom

The bathroom module has great resemblance with the kitchen, however, the method of production is very dependent on the introduction of consumer choice. Since the bathroom can be constructed using two methods in the production process of CascoTotaal.
In the first method, the bathroom is completely prefabricated in another factory and is then transported as a complete unit to the finishing factory where it is installed. When this method is chosen for the production consumer choice is almost not possible except on a large scale. The prefabricated bathrooms are produced with a minimum of 20 per design and only allow for small changes like the colour of the tiling to be incorporated per design.
However, there is a second process where the bathroom is constructed directly into the structural unit within the finishing factory. The consumer preferences can then be incorporated more easily. When the bathroom is constructed in the finishing factory, this will have a greater impact on the surrounding processes since it will take more time to construct the entire bathroom in the finishing factory as would be placing a finished prefabricated bathroom module in the structural work. When the bathroom is constructed in the finishing factory this would also have a larger impact on the inbound logistics since there are more products coming to the finishing factory that will all have to be coordinated so that the right product is delivered at the right time for the right unit. The process implications of the bathroom module when it is constructed at the factory will shift the CODP from the bathroom manufacturer towards the finishing factory (sub-contractor constructing the bathroom). The possibilities for the consumer can however be compared to the possibilities of the kitchen with the difference being that the kitchen is constructed in a different factory and transported as subassemblies while the bathroom is partly subassembly and partly locally constructed.

7.3 Consumer preference in housing design

Previously it has been seen that in the current process of CascoTotaal the perceived CODPs do not match the actual possible CODPs and that with the current limitations, the possibility for consumer influence is higher as currently offered. Since not all the possibilities for choice are preferred evenly by the consumer, the preferred amount of consumer influence with regards to customisation needs to be researched. As described in the case study protocol, the results of the study performed by (Hofman et al., 2006) will be used as a reference for the preferences of (future) house owners. In order to translate the measured preferences to CODPs, the housing components as measured by (Hofman et al., 2006) are first categorised into the product modules of CascoTotaal (Table 9). In this matrix, the impact of the housing component is translated to product modules for CascoTotaal. It can be that a housing component; only impacts a single module, multiple modules or no modules at all because it is not part of the final product that CascoTotaal produces.

Table 9: Housing preference relation matrix for CascoTotaal

Housing components / ***Product modules***

Product modules	Pavement	Extra (Solar system)	Playground and green area	Type of security system	Roofing finish	Width of house	Parking facilities	Plot layout	Facade finish	Position of water taps (cold/warm)	Number of bathrooms/toilets	Position of inner doorways	Choice type of roof	Position toilet	Casing (type and material)	Door hardware (locks and latches)	Heating system (boiler, water heater)	Depth of house	Inner casements and doors	Position of washbasins	Position of bathroom	Facade Front (openings)	Facade Back (openings)	Roof construction (dormer/window)	Type of heating (floor, wall)	Number of bedrooms	Dimensions of living room	Placement of sockets/switches	Position of kitchen	Telecommunication	Interior wall finish	Floor finish type	Tiling (type and colour)	Sanitary facilities
Structural work						×							×					×			×	×	×	×	×			×	×	×				
Interior layout											×	×		×					×		×					×	×		×					
Technical systems		×		×						×	×			×			×			×	×				×			×	×	×				
Interior finish																															×	×	×	
Exterior finish					×				×				×		×	×						×	×											
Kitchen										×										×								×	×			×	×	×
Bathroom										×	×			×						×	×							×				×	×	×

Structural work

By analysing the matrix for the structural work it can be seen that the preferences of consumers do have a high impact on the structural work. However, by further analysing the outcome on the component level, it can be seen that the housing components are divided into two categories. The first category includes six housing components which are all load bearing structural sections: Roof construction, Façade Back, Façade Front, depth house, choice type of roof and Width of house. The second category of housing components in the structural work are: Telecommunication, Position of kitchen, Placement of sockets/switches, Type of heating and Position of bathroom. These components are all situated within the structural work in the form of installations but are not constructed as a structural work part. The position of bathroom and kitchen for example dictate where the water and electrical lines need to be placed in the structural concrete walls in order to facilitate the kitchen and bathroom modules. The position of washbasins and toilet are not counted in the structural work since these are part of the kitchen and bathroom position.

Interior layout
For the interior layout, the introduction of consumer choice impacts the placement of the inner wall construction, the position and size of the inner door openings and the turning direction of the inner doors. This can also be seen in the relation matrix, the position of the kitchen, bathroom and toilet (if separated from bathroom) all dictate where the inner dividing walls for these modules have to be placed. The number of bedrooms, bathrooms/toilets and the dimensions of the living room also impact the placement of the inner walls since it will always be a trade-off. The maximum dimensions are dictated by the outer walls of the structural work. The positioning of the inner doorways informs the interior layout where openings in the interior walls are required and the inner casements and doors impact the locations of these openings even more since these dictate the size of these openings and the turning directions of the inner doorways.

Technical systems
Within the technical systems, the choice in Telecommunication and Type of security system, even though these are not directly part of the defined technical system module do impact the module. The Telecommunication is installed by the same sub-contractor as the electrical system. Therefore, the Telecommunication impacts the technical systems as part of the electrical components. The Position of: kitchen, toilet and bathroom also impacts the technical system since these components dictate the positioning of the electrical system, the water system and the ventilation system. Besides the position, the number of bathrooms/toilets also dictates the size of these system. The heating system is influenced by the type of heating (floor, wall) and the actual choice in heating system (boiler, water heater). The water system is impacted on a more detailed level by the positioning of the washbasins and the positioning of the water taps. On a higher-level of detail, the electrical system is dictated by the positioning of sockets/switches and the choice to incorporate a solar power system or not.

Interior finish
For the interior finish, only two of the three defined components by the current situation modularisation for CascoTotaal are measured in the study. Tiling impacts the wall and floor finish as defined in this research, the Floor finish impacts the module interior finish component of floor finish and the Interior wall finish impacts the module component interior wall finish. Ceiling finish as defined in the modularisation has no impact according to the measured components.

Exterior finish
For the exterior finish, the impact of consumer choice is very diverse. The influence consumers prefer to have on the actual finish of the exterior with regards to the wall and roof surfaces is directly measured by the housing components Façade- and Roofing finish. However, the exterior finish is impacted by more than just the actual finish. The windows for example are dictated by the casing choice. And the actual roof finish is dependent on the type of roof chosen. Also, the door hardware is part of the exterior finish since this is part of the exterior finish module as categorised by the modularisation. The last factor that is influencing the exterior finish modules are the Front- and Back Facades. These two dictate the positioning and dimensions of the windows and doors and the actual surface that is left for exterior wall finishing.

Kitchen and Bathroom
Since the components of consumer choice that influence the kitchen and bathroom are very similar, these two are put together. First the position of the kitchen and the bathroom, even though these are completely different in the house, impact the modules in a similar way. The positioning of the modules dictates the usable space in the floorplan of the house. Both modules also include sanitary facilities that are measured. The same is true that both modules are finished with tiling. If the bathroom is prefabricated this is done in a different factory. But if there is more choice in the bathroom, both the tiling of the kitchen and bathroom are fitted separately in the finishing factory of CascoTotaal. The same is true for the floor finish of the kitchen and bathroom which are constructed after the modules are placed, but are part of the total module. The positioning of washbasins and water taps electrical sockets/switches is also part of both modules since these have to be known before the modules are placed but are an integral part of the modules. However, the positioning of the toilet is only applicable for the bathroom and the same is true for the choice in number of bathrooms/toilets.

Now that all the modules have their impacting housing components assigned, it becomes clear that there are four housing components that cannot be categorised as part of any module. These four housing components are: Plot layout, Parking facilities, Playground and green area and Pavement. These housing components cannot be categorised in any module since they are all impacting the surrounding environment of the house, since the product of CascoTotaal does not include the surrounding environment, these housing components are not part of any module as defined in the modularisation. Therefore, they are not further analysed in this research.
With the above defined modularisation of the expressed preferences, the next section will calculate the amount of expressed preference and use this to create the most feasible CODPs positioning per product module for CascoTotaal.

7.4 Consumer preference calculations

In order to determine the most feasible CODPs based on consumer preferences as described in the case study protocol, the measured preferences from (Hofman et al., 2006) are added to the relation matrix of the previous section (Table 10).
As conclude in the previous section, four housing components could not be categorised as part of a product module. Therefore, in the analysis of the most feasible CODPs based on consumer preferences, these four housing components will not be used in the calculations.
As described in the case study protocol, the generational variety index (GVI) (Veenstra et al., 2006) is used to determine the product modules that are most likely subjected to change over time. The GVI is calculated per product module by adding all the separate relative importance's of the associated housing component together. The results of the GVI scores are presented in Figure 37.
To get a better view on the most influenced modules and the difference between the modules the absolute GVI is translated to a relative GVI score with the following equation.

$$GVI_{relative} = \frac{GVI_{module}}{\sum GVI_{module}} \times 100$$

Modules with a high GVI and high relative GVI require more have a higher impact on the process when it comes to the implementation of consumer preferences within these modules. The GVI does not measure the preferences of consumers directly per module. This is because the GVI is a summation of all the housing components per module. Modules with more components generally have a higher GVI score and score better on the relative GVI score when compared to modules with a lower number of housing components. Therefore, a different method is also needed in order to translate the preferences of the consumers to the modules in a more representative way.

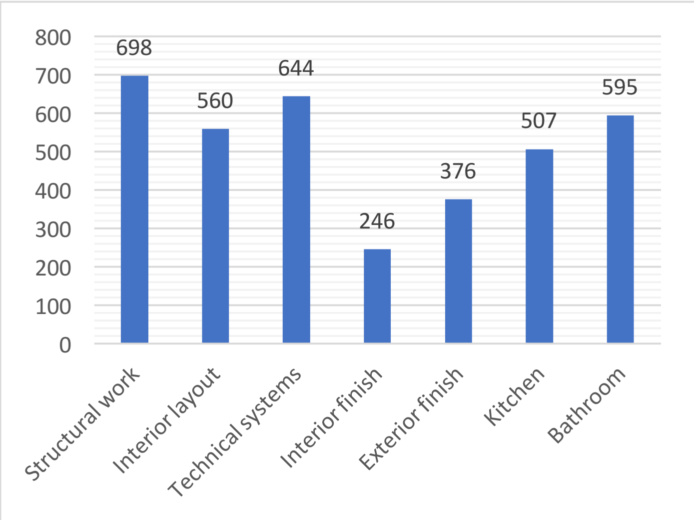

Figure 37: GVI scores per product module

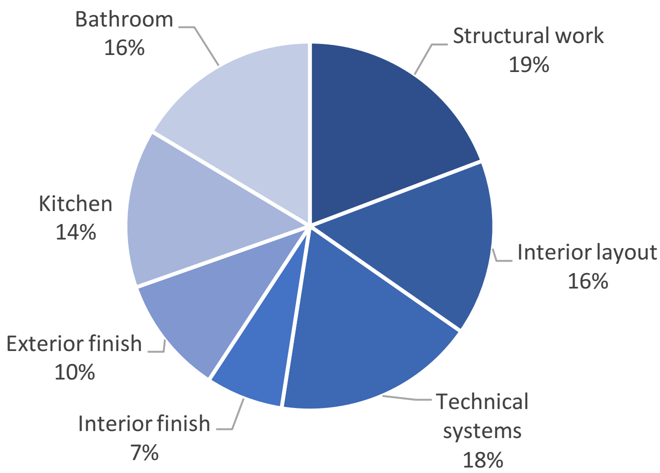

Figure 36: Relative GVI per module

Table 10: GVI calculations for CascoTotaal

Housing components	Structural work	Interior layout	Technical systems	Interior finish	Exterior finish	Kitchen	Bathroom
	Product modules						
Sanitary facilities						87	87
Tiling (type and colour)				87		87	87
Floor finish type				81		81	81
Interior wall finish				78			
Telecommunication	75		75				
Position of kitchen	74	74	74			74	
Placement of sockets/switches	73		73			73	73
Dimensions of living room		72					
Number of bedrooms		71					
Type of heating (floor, wall)	68		68				
Roof construction (dormer/window)	65						
Facade Back (openings)	64				64		
Facade Front (openings)	63				63		
Position of bathroom	60	60	60				60
Position of washbasins			59			59	59
Inner casements and doors		59					
Depth of house	59						
Heating system (boiler, water heater)			57				
Door hardware (locks and latches)					55		
Casing (type and material)					55		
Position toilet		54	54				54
Choice type of roof	54				54		
Position of inner doorways		49					
Number of bathrooms/toilets		48	48				48
Position of water taps (cold/warm)			46			46	46
Facade finish					46		
Width of house	43						
Roofing finish					39		
Type of security system			26				
Extra (Solar system)			4				
Absolute importance (GVI)	**698**	**560**	**644**	**246**	**376**	**507**	**595**
Relative importance (GVI_r)	**19**	**15**	**18**	**7**	**10**	**14**	**16**
Average importance	***63,5***	***62,2***	***53,7***	***82,0***	***53,7***	***72,4***	***66,1***

A way to get a better view on the importance consumers express towards the different modules of CascoTotaal is to calculate the average importance expressed in the survey per module. The average importance is calculated by adding all the relative importance per module together and dividing this number by the number of housing components active in the specific module. The calculations of the average consumer preference importance Figure 38. The final step in the process of determining the consumer preferences is analysing the possible gap between the relative GVI and the relative average importance expressed by the consumers Figure 39. The relative average importance is a relative number of importance per module. The relative average importance represents the influence of offering consumer based customisation on the satisfaction of the consumer per product module relative to the other product modules. The relative GVI measures the impact on the process per module when offering consumer based customisation relative to other modules.

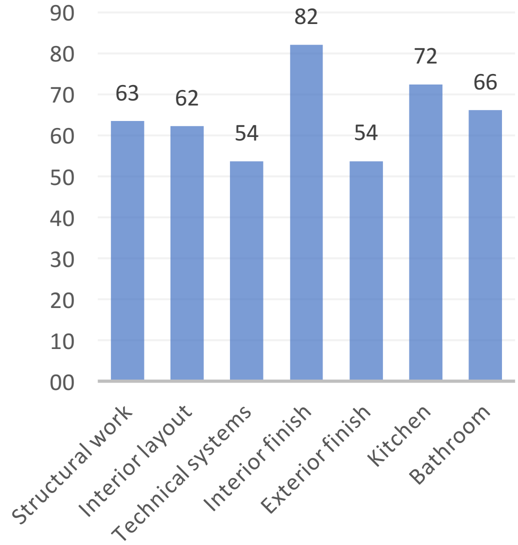

Figure 38: Average consumer preference importance

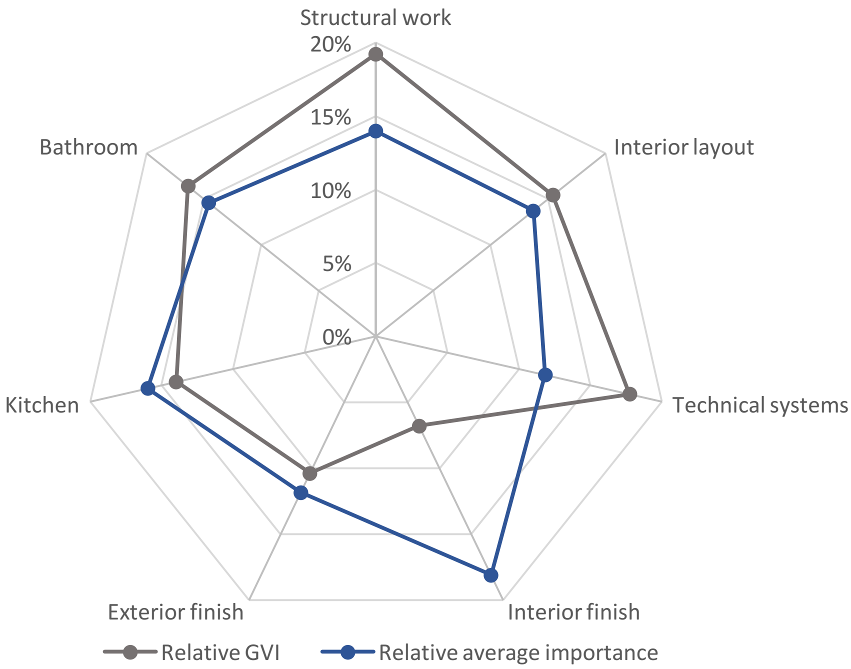

Figure 39: Preference gap analysis

By analysing the difference between relative GVI and relative average, the difference between the impact on the process and consumer satisfaction of offering choice can be found per product module. If a gap between the two lines of Figure 39 exists, this means that there is a gap between the relative importance and the average of the module. The positioning of the lines and the distance between them per module indicates the impact when offering consumer based customisation in the module. A good example can be seen in the Interior finish module. The low relative GVI score of the Interior finish can be explained because it only includes three housing components. This can be translated to a low influence on the process level when consumer preferences are incorporated in the interior finish module. However, the line of relative average importance is very high, this means that for the consumer choice is very important in the interior finish module relative to the other modules. The large gap between the relative GVI and relative average importance shows that with relatively few changes in the process structure, relatively high consumer satisfaction with regards to consumer choice can be achieved.

For the technical systems module, the opposite effect can be seen. Here, the relative GVI is higher compared to the Relative average, indicating that when consumer choice is incorporated in the module of the technical systems, the implications to the process structure will be greater as the increase in consumer satisfaction. The conclusion can therefore be drawn that offering consumer choice in the technical systems module will have relatively more consequences for the process as would be implementing consumer choice in the interior finish module. With this information, the preferred CODPs based on consumer preferences can be constructed in the next section of this chapter.

7.5 Preferred CODPs for CascoTotaal based on consumer preferences

In order to find the CODPs mapped according to the preferences of the consumer, the preferences expressed per product module first need to be translated to CODPs. For this a mapping is made based on the average importance. Following the case study description, the CODPs are mapped according to three preference categories; High preference, Medium preference and Low preference. Also, the CODPs can have five different placements following the previously used customisation levels of (Barlow et al., 2003); Pure Customisation, Tailored customisation, Customised Standardisation, Segmented Standardisation and Pure Standardisation. In order to translate the expressed importance to a CODPs matrix as described in the case study protocol, the category intervals have to be determined. For the category intervals the formula of class interval is used as described by (Silver, 1997):

$$Class\ interval = \frac{Data\ Range}{Number\ of\ categories\ required}$$

In order to use the formula, the unknowns have to be determined. The result will be the class interval rounded to an integer (whole number). The data range used for the determination of the class interval will be the possible range of expressed importance on the housing component level. Since the lowest importance level is 0 (not important at all), and the highest is 100 (everyone in the study finds this the most important). The range of possible data is will be one hundred minus zero (100 – 0), which will give a data range of 100. For the number of categories required there is a difference between the X-axis of the matrix and the Y-axis of the matrix. For the X-axis, there are three categories; High, Medium and Low. Therefore, the required number of categories is three (3). The class interval for the X-axis can now be calculated:

$$Class\ interval = \frac{100 - 0}{3} = 33{,}333$$

The class interval calculated is 33,333 per step. However, the closest integer is 33. Therefore, the class interval used will be 33, starting at 0 and ending at 100.

For the Y-axis, there are the following categories; Pure Customisation, Tailored customisation, Customised Standardisation, Segmented Standardisation and Pure Standardisation. Resulting in a number of categories required of 5. When the formula is now used, it will look like this:

$$Class\ interval = \frac{100 - 0}{5} = 20$$

The class interval for the Y-axis will be 20, Starting at 0 and ending at 100. In order to now compile the preferred CODPs matrix based on consumer preferences, the Product modules are plotted in the matrix based on their average consumer preference importance resulting in the matrix as seen in Figure 40.

As described in the case study design, the matrix is an adopted version for this research from the original as used by (Schoenwitz et al., 2017). By plotting the average consumer preference importance, the preferred level of customisation can be determined for the product modules as described in the modularisation. The higher the expressed preference, the higher the level of customisation per module should be. The matrix also gives a spread of possibilities for customisation level which are acceptable in the form of the white area of the matrix. The module should fall within the white area, the maximum spread of customisability offered to the consumer is than dictated by the preference level. For example, a module categorised as a medium level consumer preference module should have customisation options between Segmented Standardisation and Tailored Customisation in order to satisfy the consumer needs.

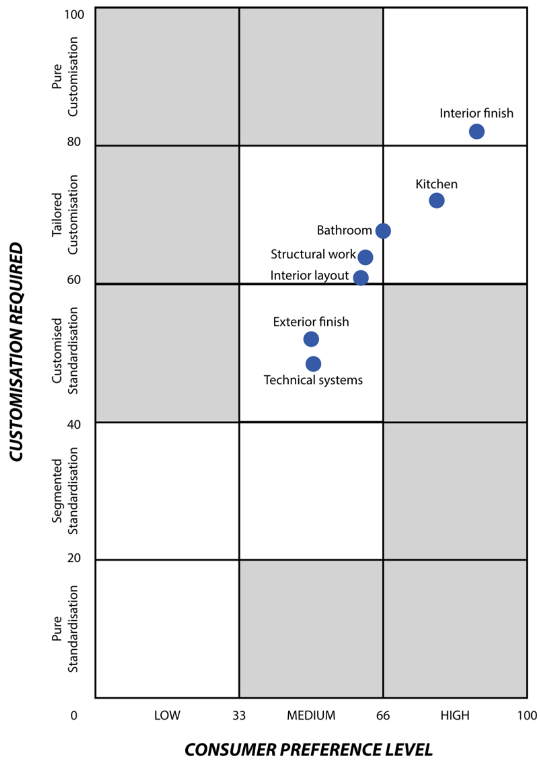

Figure 40: Preferred CODPs matrix of CascoTotaal

By analysing the Preferred CODPs matrix of CascoTotaal it can be concluded that the preferred CODPs based on customisation preferences are all within tree customisation levels. The Interior finish is preferred to have the highest possible level of customisation where the interior can be completely customised to the consumers linking. The Kitchen, Bathroom, Structural work and Interior layout are all categorised as Tailored Customisation. This can be explained since these modules are all interconnected with each other on a component level, meaning that if something is changed in one of these modules, another of these modules is also subjected to changes. An example can be found in the positioning of the kitchen and bathroom. If the layout of these change, the Interior layout can be impacted based on the preference expressed. Also, the structural work has to facilitate these changes with regards to: connection points and pipework inside the structural walls. The conclusion from this interrelation is that if the customisation level of a module that has much interrelating components is changed, the customisation level of the other modules with the same interrelating components will change also. The last two and lowest levels of consumer preferred customisation levels are those of the Exterior finish and Technical system modules. Both have the categorisation of Customised Standardisation where there is limited choice from a predefined choice set offered to the consumer.

By adding the preferred CODPs to the previously made CODPs mappings, the difference between the CODPs of the current process for the customer, the perceived CODPs of the consumer and the preferred CODPs of the consumer can be compared (Figure 41).

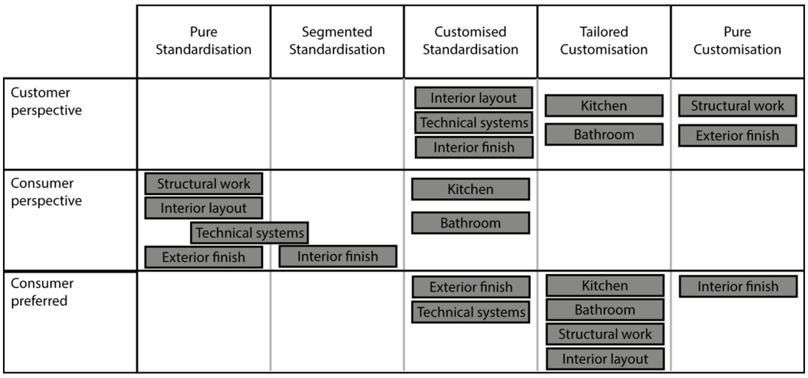

Figure 41: Preferred CODPs compared to current situation

The positioning of the preferred CODPs as presented in Figure 41 would be the ideal situation if the consumer preferences for each module are directly incorporated into the process of CascoTotaal. However, if these preferred CODPs are compared to the CODPs from the perspectives of the consumer and customer it is seen that there is a difference in preferred and actual CODPs placement in the process. Change is therefore recommended in the process to better incorporate the consumer's preferences and thereby increasing their product satisfaction. But it is not always possible to incorporate the preferences of the consumer directly into the process. Therefore, the most feasible placement of the CODPs need to be explored for the process of CascoTotaal.

7.6 Most feasible CODPs for CascoTotaal based on consumer preferences

The preferred CODPs as analysed in the previous section are a representation of the consumer preferences on the product of CascoTotaal when no restrictions apply. However, as seen previously, some restrictions to the; process, logistical and technical possibilities do apply for the product and process of CascoTotaal. Besides these restrictions, the impact on the different modules when compared to the effect consumer based customisation has on the satisfaction per module as seen in the preference calculations varies per product module. Therefor in order to find the most feasible CODPs mapping for CascoTotaal, all these restrictions, possibilities and other factors have to be incorporated in the previous consumer preferred model of CODPs in order to find the most feasible map of CODPs for CascoTotaal. This most feasible map will be the final CODPs map created in the creation of the future situation and will be used as the input of the effects mapping of consumer preferences incorporation on the supply chain and external effects in the next chapter.

7.6.1 CODPs spread

In order to find the most feasible positioning of the CODPs first the possible spread of the positioning per module is determined from the preferred CODPs mapping. The possible spread of positioning the CODPs is dictated by the white area of the preference matrix as discussed in section 7.5. An example of the possible spread for the Exterior finish module is given in Figure 42.

The blue dot represents the expressed preference as based on the average importance. The spread is represented by the two arrows above and below the preferred positioning indicating that the actual positioning can shift up or down along this line without significant impact to consumer satisfaction. The blue shaded area in the matrix repents the current perceived CODP of the process while the orange shaded area represents the current CODP for the customer. As seen for the exterior finish, the possibilities given to the customer are above the spread, meaning that more customisation is possible as required to satisfy the consumer. While the CODP from the consumer perspective is below the spread and therefore, for the consumer, the customisation is to limited at the moment.

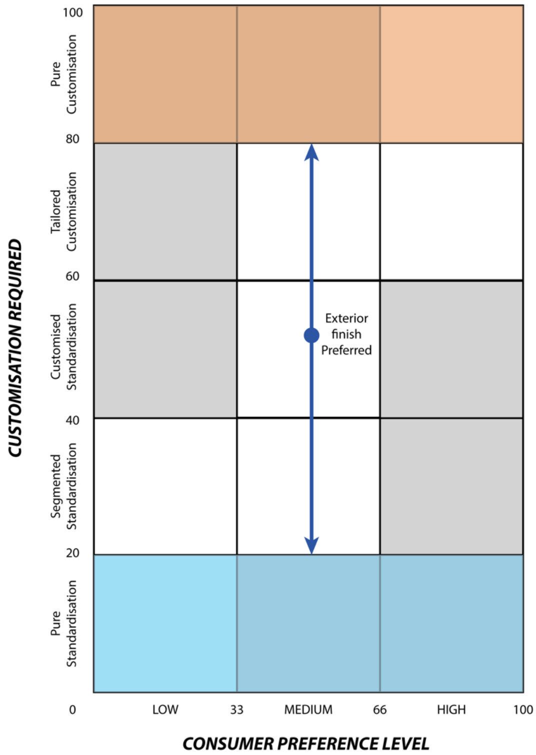

Figure 42: CODP spread for the Exterior finish module

The analysis on the possible spread of the CODPs for the process of CascoTotaal has been performed for all defined product modules and can be found in Appendix V. The results of the CODPs spread analysis is summarized in a visual representation as seen in Figure 43. The bars indicate the possible spread of the modules while the placement of the module's name indicates the preferred positioning of the CODPs according to the consumer preferences. As seen in the results, most modules have a large spread of possible CODPs possible in order to satisfy the needs of the consumer without significant influence on the satisfaction of the consumer even though the preference for customisation is on the higher side.

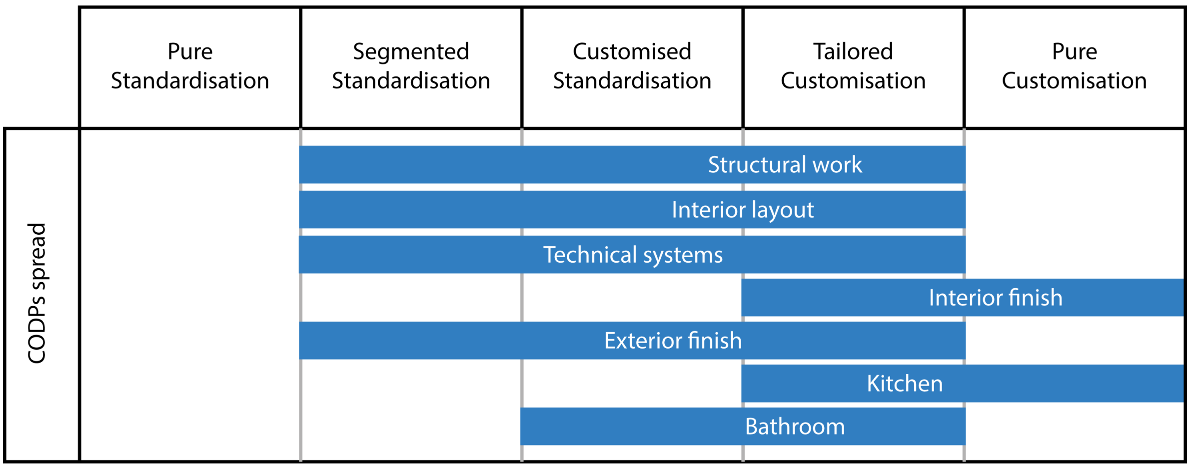

Figure 43: CODPs spread analysis results

By analysing the spread of the CODPs, the most preferred positioning according to consumer preferences is created, and the spread indicates the area of the CODPs to move without significant change in consumer satisfaction. In order to now transform these spreads into the most feasible CODPs placement for CascoTotaal the limitations and possibilities as analysed in section 7.2 will be combined with the preferred placement and spread in order to find the trade-off between standardisation and customisation.

7.6.2 Customisation trade-off

In this section, the final trade-off between standardisation and customisation is made as described in the conceptual model of chapter 2.2 (Figure 44). The Consumer preferences from the conceptual framework is measured and mapped for the process of CascoTotaal in the previous sections. The Level of standardisation is also explored with the acceptable level of standardisation being visualised as the possible spread of the CODPs per product module. Now both concepts are combined with the earlier researched possibilities and limitations of the production process and product of CascoTotaal in order to find the Customisation Trade-off. The customisation trade-off will result in the most feasible CODPs mapping and will be used as an input for the effects mapping in the next chapter.

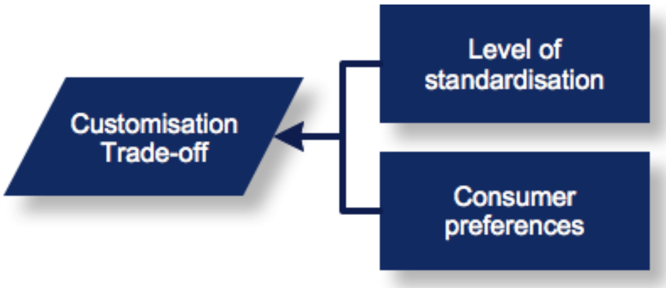

Figure 44: Customisation trade-off

Structural work

The current positioning of the CODP for both the consumer and customer do not match the preferred level of customisation. The customer level is too high and the consumer level is too low. As seen in the supply chain and process mapping of the current situation analysis, the structural work is the input for the rest of the process since all other modules are fitted to the structural work. Also, as seen in the relation matrix, other modules are impacting the build of the structural work and the module itself is limited by technical and logistical factors with regards to maximum dimensions and a weight possible. Besides this, the production of the structural work can be limiting since some steps in the production process are very labour intensive and are not feasible to perform differently for every unit produced.

From Figure 39 it can be concluded that the relative impact on the process is higher as the relative gain in consumer satisfaction when customisability is increased for the consumer. However, the current CODP of the customer is above the preferred customisability level, therefore it can be concluded that with the current process it should be possible to increase the current level of customisability for the consumer since the positioning of the consumer at the moment is below the acceptable spread.

The feasible level of customisation on the consumer level would then be Customised Standardisation or Assembled-to-order. The module will be mostly standardised; however, some choices can be made possible without significant influent on the current process. As seen in the limitations, the setup of dimensions and wall openings for the structural work are very process intensive steps therefore, these steps are preferred to be standardised in the process of CascoTotaal. It would preferable to not let the consumer choose the length and/or width of the unit. However, in the technical installations of the structural work, consumer choice can be realised since these have to be set up before concrete casting according to a premade drawing for every unit individually. The only difference would be that the drawing will change per unit. All the materials needed are stocked products, therefore, positioning of the kitchen and bathroom or the type of heating can be left to the consumer. The structural work as perceived by the consumer will then change from Pure Standardisation to Customised Standardisation where every unit is slightly different and assembled to order from stocked components and comply with the requested customisation spread determined before.

Interior Layout

In the current positioning of the CODP, the consumer perspective is below the spread and the customer is within the spread but below the determined preferred level. Figure 39 showed that the lines of consumer satisfaction gain and process impact are very close meaning that the limitations determine the most feasible level. From the limitations analysis, it became clear that there are no technical limitations to the construction of the metal stud walls and no significantly limiting logistical factors. However, Pure customisation cannot be reached since the interior layout is limited to one fixed position wall in the floorplan. Also, the sub-components that the walls are made of cannot be changed since other modules like the technical systems rely on the walls being made from a metal stud construction. Therefore, the most feasible positioning of the CODP would be a Customised Standardisation where the layout except for one wall is completely free to the consumer's preferences, but the construction of the walls and the components that are within the module are limited to a metal stud construction.

Technical systems

For the technical systems, the current customer positioning of Customised Standardisation matches the preferred level of the consumer. However, the level of the consumer is below the spread. From the limitations analysis of the technical systems unit it has become clear that there are implications for the technical systems since it is dependent on other modules. Also, there are technical limitations because all the components have to be able to fit together and match the required capacity. Since it is not preferable for CascoTotaal to let the consumer totally free in the choice of components as this would have to great of an impact on the process, a limited level of customisation should be strived for higher as the current level perceived by the consumer.

The most feasible customisation level for the consumer would be the level of Customised Standardisation where there is a predefined set of choices throughout the technical systems, like the placement of sockets and switches or the type of heating but these choices are on a higher level. The lower level of design and parts is not left to choose by the consumer since this would be undesirable with regards to complexity. Nevertheless, the level of Customised Standardisation for the consumer will be within the proposed spread of possible CODPs.

Interior finish

For the interior finish, both the positioning of the CODPs from the customer and consumer perspective do not meet the required spread This can be allocated to the structure of the current process where there is very limited choice of standardised products and it is chosen to not finish the walls and floors other than for the kitchen and bathroom. However, in Figure 39 it was seen that by providing choice options to the consumer, the impact on the process is relatively low and the achieved satisfaction is relatively high. Also during the limitations analysis, it was found that there are no technical limitations. Therefore, it would be advisable to incorporate a high level of customisation for the module of Interior finish. The minimum level of customisation should be Tailored Customisation where the consumer can choose from selected components to finish the house. However, the option to not include interior finish can also be an option for the consumer but should not be forced by the customer. Higher levels of customisation are unfeasible since the logistical and process implications would be to significant due to the increased number of components. But, with an increase to Tailored Customisation, the module will fall within the CODP spread.

Exterior finish
As seen in Figure 39 the relative impact on the process for exterior finish is lower as the relative importance expressed by the consumer. Therefore, incorporating consumer choice with regards to the exterior finish of the house can have a positive effect on the consumer satisfaction. The current positioning of the consumer is Pure Standardisation since the consumer at the moment has no choice at all. However, the positioning of the customer is Pure Customisation while the preferred level of the consumer is placed at Customised Standardisation. When the limitations of the exterior finish are analysed, it is seen that there is a technical limiting factor in the form of the insulation thickness. When a certain insulation value is needed, the thickness of the insulation will have to be adjusted accordingly. This is a choice that is preferred not to be made by the consumer. Therefore, the choice in insulation would be limited. The exterior finish with regards to façade and roofing finish are far less limiting and can therefore be left to the consumer if preferred. However, it is seen in the preference matrix that these two components do not have a very high score of expressed preference. Also, if the exterior is finished using brick-slips there are process and logistical limiting factors. Therefore, the most preferable positioning of the CODP for the exterior finish for CascoTotaal would be Customised Standardisation.
The positioning of Customised Standardisation can be achieved when there are subsets of choice options created by the suppliers for the consumers to choose from with regards to exterior façade, roof and door finish. However, the process intensive components such as the insulation will not be offered as a choice but are related to the energy norm the complete house has to oblige to as defined by the customer.

Kitchen
For the current positioning of the kitchen as perceived by the customer, the level is at the preferred level of Tailored Customisation. The level of the consumer however, is too low at Customised Standardisation. Since the relative impact on the process is lower as the relative average importance in Figure 39, it is preferable to offer more customisation in this module since it has relatively more consumer gain as process losses. When compared to the limitations of the kitchen it is seen that the kitchen modules are produced at the factory of the kitchen supplier. The effect to the process of CascoTotaal are therefore limited and a higher level of customisation for the consumer can be realised. From interviews at the kitchen supplier of CascoTotaal it has become clear that Pure Customisation is not possible since the kitchen supplier works with certain standardised products for the appliances and sanitary fitting. However, for the cabinets and countertops Pure Customisation is possible as long as the budget of the consumer allows it. Therefore, the most feasible positioning of the kitchen would be between Pure- and Tailored Customisation if the budget of the consumer allows it.

Bathroom
The current positioning of the CODP for the bathroom of both the consumer and customer perspective are within the spread. The customers positioning is Tailored Customisation and therefore is fully compliant with the preferred positioning. The consumer's perspective is currently at the positioning of Customised Standardisation, which is also within the acceptable spread. However, these positioning's are made with the current concept where the bathroom is constructed in the finishing factory of CascoTotaal. As seen in the limitations, the second option would be to install prefabricated bathrooms. However, if this would be done, the positioning of the consumer would be lowered to the level of Pure standardisation

and when some small choices are added to a level between Pure and Segmented Standardisation. However, if more choice options for the consumer are added to the current construction process, which is possible according to the current bathroom supplier, the perspective of the bathroom for the customer would reach the level of Tailored customisation. The most feasible level for the bathroom for CascoTotaal would therefore be the Tailored Customisation level in order to create a better fit to the consumer preference.

Now that all the most feasible CODPs from the consumer's perspective have been determined for the separate modules, the final CODPs mapping can be made (Figure 63). The mapping visualises to most feasible placement of the CODPs of every module in one figure. The CODPs are mapped according to the most feasible placement as determined above and represented in Figure 63 as the dark blue areas. The light blue area represents the preferred spread of the CODPs. As seen, all the most feasible CODPs are now placed within the preferred spread as expressed by the consumer.

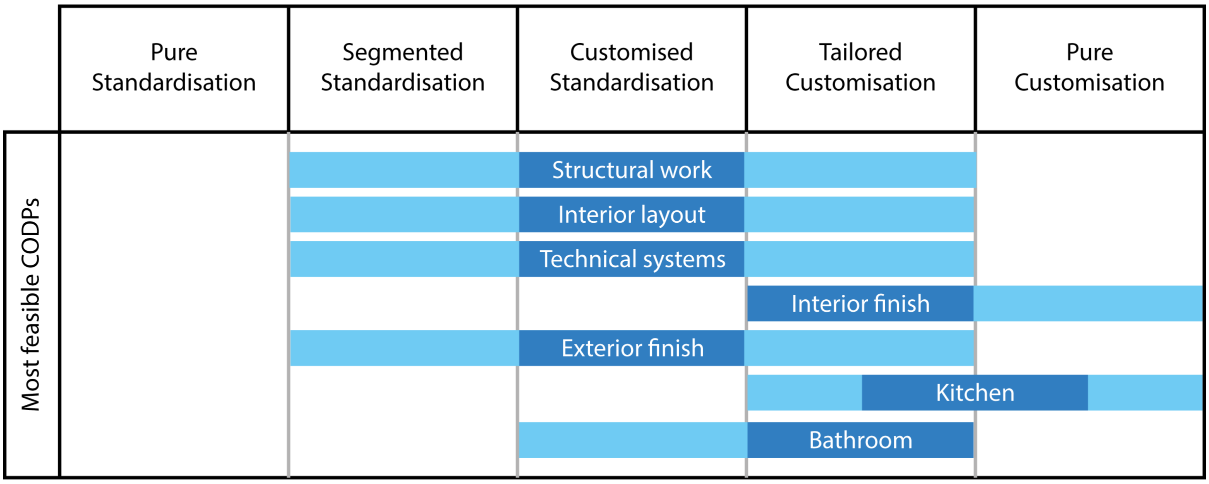

Figure 45: Most feasible consumer CODPs mapping for CascoTotaal

With this mapping of the most feasible CODPs for the process of CascoTotaal based on consumer preference and adjusted to the limitations of the current process, sub-question 5 is answered. Together with the current situation map of the CODPs from the previous chapter, the most feasible map will be used as an input to the effects mapping in the next chapter of this report in order to find the influence of incorporating consumer preference in the process of industrialised housing construction at CascoTotaal.

8 Effects mapping for CascoTotaal

In this chapter, the effects of repositioning the CODPs from their current position, as found in the current situation analysis of chapter 6, to the most feasible position, as found in chapter 7, will be analysed (Figure 46).

The analysis first performs a test for alignment between the current and most feasible positioning of the CODPs. From the test for alignment, the found gap, if there is a gap present, will be analysed in order to find the effects of offering consumer choice in industrialised housing construction. The effects will be categorised into one of two categories. The first category will include all the internal process effects and supply chain effects, the second categorisation will be the effects on the surrounding outside world of the process or the external effects.

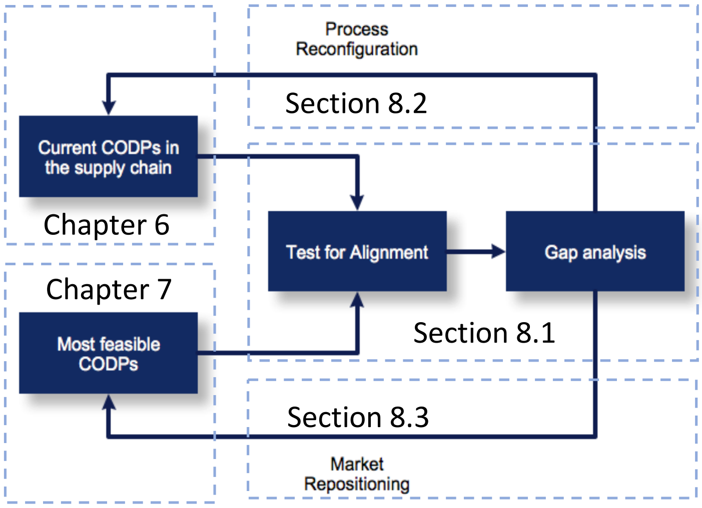

Figure 46: Chapter 8 Effects mapping for CascoTotaal

8.1 CODPs test for alignment and gap analysis

During the test for alignment, the determined positioning's of CODPs for the; customer, consumer and most feasible process are compared to each other. As seen in Figure 46, the input for the test of alignment are the current positioning's of the CODPs and the positioning of the most feasible CODPs per product module. All positioning's are compared and if there is a gap present between them, options to close the gap are proposed based on previous data presented in this report. The output of the gap analysis is then categorised into one of two streams of impacts. The first stream is where the found knowledge is transferred back to the internal process via a process reconfiguration. This will be the input of the supply chain effects later on in this chapter. The second stream of outputs is fed back into the most feasible positioning of via a market positioning of the product. and will form the main input for the mapping of the external effects later in this chapter.

8.1.1 Structural work analysis

Starting with the Structural work module, the CODPs from the customer and consumer are first mapped from previous results in this report. These CODPs are then compared to the most feasible CODP and the possible spread as determined previously (Figure 47). By taking the most feasible CODP (represented as the dark blue section of the spread) and comparing it to the current perceived CODP of the consumer it can be seen that there is more customisation needed in the structural work module in order to satisfy the consumer.

	Pure Standardisation	Segmented Standardisation	Customised Standardisation	Tailored Customisation	Pure Customisation
Customer					Structural work
Consumer	Structural work				
Most feasible			Structural work		
Component	Mounting hardware Concrete	Installation materials			Rebar

Figure 47: Test for alignment Structural work

The level of customisation possible for the customer is far above the most feasible level of customisation however, this can be explained in the number of products the customisation is translated to. The customer determines the changes in the structural work for all the houses being built for that customer (at the moment there is a minimum production run of 10 units per customer). Therefore, the level of customisation present at the customer level is not for the individual houses, but for the entire order amount of the customer (all houses in that production run). It is also not feasible, as discussed in the limitations analysis, to let the consumer have as much influence on the structural work as the customer since this is on economical and process level not feasible. The dimensioning of the structural units is and will for example not be transferred to a choice of the consumer.
From the customisation trade-off analysis performed in section 7.6.2, it was also seen that the structural work is depended of other modules in order to determine the impact of the customisation. For example, the positioning of the kitchen and bathroom determine for a large part the installation materials needed in the concrete walls and therefore offering more customisation in the kitchen and bathroom will also increase the level of customisation of the structural work. Besides this, it was determined that on the component level, the only feasible possibility for customisation to consumers was in the installation materials, and the only feasible possibilities for increasing the level of customisability in the structural work with regards to the installation materials is in the positioning of the sockets and switches for the outer- and interior concrete walls.
In order to achieve an increase of customisability for the consumer, the level should increase from Pure Standardisation where nothing is adjustable to the level of Customised Standardisation where the consumer can influence the assembly of the module. As seen previously, the customisation level for the structural work is largely determined by other modules and therefore the level will automatically increase if the kitchen and bathroom increase in customisation levels when features are incorporated in the structural work concrete walls. However, the technical installations in the concrete walls will also have a large impact on the CODP positioning of the consumer. Therefore, it is advised to at least let the consumer have a choice in the technical installations (installation materials component of the structural work) to be applied in the structural work.

8.1.2 Interior layout analysis

For the interior layout, the test for alignment of Figure 48 shows that there is no gap present for the positioning of the CODP from the customer perspective, but the consumer does not have enough influence on the module when the CODP positioning of the consumer is compared to the most feasible CODP positioning.

On the component level of the interior layout it is seen that all components are locally stocked products as also seen in the SCOR thread diagram. This means that in order to increase the customisation level for the consumer, the incorporation of these components in the module itself needs to be changed.

	Pure Standardisation	Segmented Standardisation	Customised Standardisation	Tailored Customisation	Pure Customisation
Customer			Interior Layout		
Consumer	Interior layout				
Most feasible			Interior layout		
Component	Gypsum board Metal profiles				

Figure 48: Test for alignment Interior layout

The level of Customised Standardisation as required by the most feasible CODP positioning dictates that the consumer should at least have influence on the customisability of the module assembly. From the limitations analysis, it was seen that apart from the single concrete wall, there are no technical limitations to the incorporation of full customisability to the floorplan. However, the components of the module, Gypsum board and Metal profiles, cannot be changed by the consumer since this would have to great of an impact on the final product, because other modules rely on this type of wall construction. Also, changing the components could increase the weight of the final unit above the maximum allowed 30T limited by the logistical limitations of the final unit.

So, in order to increase the consumer CODP positioning for the interior layout from Pure Standardisation to the level of Customised Standardisation, the assembly of the interior layout module should be influenced by at least offering multiple layouts for the consumer to choose from. This will ensure that the consumer can have influence in the assembly of the interior layout module without significant process impacts.

8.1.3 Technical systems analysis

For the technical systems, a same situation is visible as for the interior layout in the test for alignment and gap analysis (Figure 49). The CODP positioning for the customer is sufficient. However, the positioning transferred from the customer to the consumer perspective is below the preferred level. In order to increase the customisation level of the consumer from the current positioning between Pure Standardisation and Segmented Standardisation to the most feasible level of Customised Standardisation, the consumer should at least have a say in the assembly of the module.

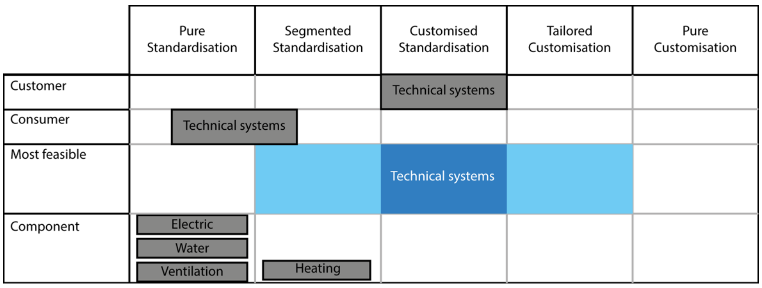

Figure 49: Test for alignment Technical systems

The components used to assemble the module are all high-level components; Electric system, Water system, Ventilation system and Heating system. These components, as can be seen in their separate CODPs, are mostly stock or Pure Standardisation products. When these four technical system components are traced back from the sub-contractor to the materials supplier in the SCOR thread diagram it can also be seen that the sub-contractor transforms the stocked Pure Standardisation products into a made-to-order product.

In order to now incorporate more customisation in the module, this is most likely to happen between the material supplier and the sub-contractor. As seen in the limitations analysis, it is preferable to incorporate consumer choice on the higher component level of the technical systems since most consumers do not possess the required knowledge to compose the total system from subcomponents. The repositioning of the CODP should therefore exist of predefined and pre-engineered sets of components for the consumer to choose from. An example of one of these choices could be the choice to incorporate solar power into the system or not. Or the choice in type of heating, where there are predefined options like; Radiator heating, floor heating or infrared heating. These options can all be engineered in advance and be incorporated in the product for the consumer, thereby increasing the positioning of the CODP for the consumer to the required level of Customised Standardisation.

8.1.4 Interior finish analysis

For the interior finish module, it is seen in the test for alignment that both the CODP positioning of the customer and the consumer are below the most feasible or preferred level of customisation (Figure 50). The main reason for the current positioning being below the most feasible level of customisation is found in the current process analysis. The positioning for the customer is found to be very limited at the moment since most of the finishing is left to the consumer once the house is handed over to them on the final construction site. Therefore, in the current process, the finishing of the floors and walls is not incorporated in the product. This is not a choice of CascoTotaal, but rather a choice of the current customers who do not want to invest in a totally finished product. For the Spero 1 single family home, there would be the possibility for interior finishing on the level of Pure Customisation for the customer. However, since this is not translated towards the consumer at the moment, the positioning of the consumer is further analysed for this gap analysis.

	Pure Standardisation	Segmented Standardisation	Customised Standardisation	Tailored Customisation	Pure Customisation
Customer			Interior finish		
Consumer		Interior finish			
Most feasible				Interior finish	
Component	Ceiling finish	Floor Finish Interior wall finish			

Figure 50: Test for alignment Interior finish

From the limitations analysis earlier in this report, it became clear that incorporating finishing for; floors, ceilings and walls is possible in the current process of CascoTotaal, and since more customisation features need to be incorporated in the current process in order to satisfy the consumer needs. As seen in the comparison analysis of process impact and customer satisfaction (Figure 39), increasing the customisation features on the component level will have a relatively large positive effect on consumer satisfaction while having a relatively small impact on the total process. It can also be seen in the SCOR thread diagram and the CODPs of the separate components that most components are relatively standardised products with some variations possible. In order to achieve the most feasible customisation level of Tailored Customisation, the consumer preferences should at least be able to be translated on the subcomponent level used to assemble the components. For the Interior finish this means that the consumer should at least be able to express their preferences on for example the colour of the ceiling finish or the material and colour of the wall finishing. However, since there are a lot of choices possible for all subcomponents of; ceilings, floors and walls, it is most feasible for the process to incorporate a basic set of finishes for every component with choice from different subcomponents in order to keep the process manageable. These sets of choices can be predefined by the customer for the consumers to choose from. By letting the customer define the choice sets for the consumer both the positioning of the customer and the consumer will increase. The positioning of the customer will increase to Pure Customisation since the customer can choose whatever their preference is to incorporate in the choice set offered to the consumer. The consumer will also increase and if the choices are diverse enough on the subcomponent level the positioning of the consumer will increase to the required level of Tailored Customisation. However, in the choices offered by the customer there should always be the choice for the consumer to not incorporate any finishes and do it themselves once the house is handed over to them, but this is then a choice of the consumer and not a choice of the customer translated to the consumer hereby still achieving the level of Tailored Customisation.

8.1.5 Exterior finish analysis

For the exterior finish module, the test for alignment shows that the CODP for the customer is above the most feasible level of customisation, but that the perceived level of customisation offered to the consumer does not meet the preferred level represented in the most feasible positioning of the CODP (Figure 51).

	Pure Standardisation	Segmented Standardisation	Customised Standardisation	Tailored Customisation	Pure Customisation
Customer					Exterior finish
Consumer	Exterior finish				
Most feasible			Exterior finish		
Component		Insulation Exterior roof finish		Window- and doorframes Exterior wall finish	

Figure 51: Test for alignment Exterior finish

The gap present between the customer, consumer and most feasible positioning of the CODP can be traced back to the current situation analysis. During the current situation analysis, it was seen that the customer is the decider for the exterior finish by designing their preferred house and then the consumer gets a couple of options to choose from on the inside of the house. However, it is seen that the consumer does prefer to have their preferences translated into the final house. The most feasible level of Customised Standardisation dictates that the consumer should at least have their preferences translated to the final product on the module assembly level by offering choices on the component level.

As discussed in the limitations analysis and during the construction of the most feasible CODP positioning, it is not preferable to give the consumer a lot of freedom in the exterior finish module since other modules are also impacted by the exterior finish. An example can be seen in the dimensioning of the structural work depending on the thickness of the exterior finish (insulation and exterior wall finish) for the maximum dimensioning. In order to achieve the required level of Customised Standardisation, the customisation features that can be offered to the consumer are found in the exterior wall- and roof finishing and in the window- and doorframes. For the exterior wall finishing, the colour of the brick slips can be changed for example if the customer wishes to use a brick finish, but then other subcomponents such as the colour of the roof tiles should also be customisable. If the customer is less focussed on a certain exterior look or finish, the entire finish can be left to the consumer with choices from multiple materials for the finishing. However, only the cosmetic exterior finish of the house should be customisable since the specialised decisions should not be left to the consumer. For example, the type and level of insulation has to be determined by the customer in order to guarantee the required energy efficiency. But, there are enough options in the exterior wall- and roof finishing in combination with the window- and doorframes to improve the positioning of the CODP for the consumer from Pure Standardisation to the required Customised Standardisation.

8.1.6 Kitchen analysis

For the Kitchen, it can be seen in the test for alignment that the CODP of the customer is positioned on the most feasible level, but that the consumer is positioned below the required level of customisation (Figure 52).

	Pure Standardisation	Segmented Standardisation	Customised Standardisation	Tailored Customisation	Pure Customisation
Customer				Kitchen	
Consumer			Kitchen		
Most feasible				Kitchen	
Component	Appliances	Tiling		Cabinets Counter tops	

Figure 52: Test for alignment Kitchen

The gap in positioning of the CODP between the most feasible positioning and the current positioning of the consumer exists since, as seen in the current situation analysis, the consumer is only offered a limited set of customisation features for the kitchen module in the assembly stage of the module itself. For every component, there are limited choices available to the consumer. In order to increase the level of customisation for the consumer, the consumer should at least be able to express their preferences on the subcomponent level with sufficient choices to achieve a classification of Tailored Customisation.
During the limitations, it was seen that there are very little limitations to the introduction of customisation in the kitchen module since the entire kitchen module is produced at a different factory and transported to the finishing factory of CascoTotaal in sub-assemblies. Therefore, customisation features are not directly impacting the process of CascoTotaal when the most influential features of the kitchen module, such as the connection point to the technical systems, stay standardised features. From interviews with the current kitchen supplier it became clear that, the kitchen is completely customisable if the budget of the consumer allows it. However, as said earlier in the construction of the most feasible CODP positioning, it is not preferable to allow complete customisability. Therefore, the main layout of the kitchen should be standardised or at the most consists of a limited number of standard layouts that can be chosen. This way the impact for every single house with regards to the technical systems and other modules can be reduced. However, the rest of the kitchen components should be completely customisable at the kitchen supplier so that the required level of Tailored Customisation can be achieved.

8.1.7 Bathroom analysis

For the bathroom module, the same situation can be seen in the test for alignment as in the kitchen module (Figure 53). The positioning of the CODP for the customer is at the right level of customisation while the level of the consumer is not at the preferred level.

	Pure Standardisation	Segmented Standardisation	Customised Standardisation	Tailored Customisation	Pure Customisation
Customer				Bathroom	
Consumer			Bathroom		
Most feasible				Bathroom	
Component	Technical systems Sanitary fittings Accessories	Tiling	Cabinets		

Figure 53: Test for alignment Bathroom

The gap between the current consumer level of Customised Standardisation and the preferred level of Tailored Customisation can just like at the kitchen module also be explained when looking at the current situation analysis. In the current situation, the bathroom customisation features are limited by the customer while during the limitations analysis it became clear that there are very little limitations for introducing customisation features to the bathroom module. However, unlike the kitchen module, constructed at another factory, the bathroom module is completely constructed at the finishing factory of CascoTotaal. This is the reason for the current limited customisation offered by the customer to the consumer. In the current situation, the choices offered to the consumer by the customer for the bathroom are limited in order to simplify the construction process in the factory of CascoTotaal. But, in order to increase the consumer positioning from Customised Standardisation to Tailored Customisation, the customer should at least be able to transfer their preferences on a subcomponent level in the bathroom module.

In order to achieve this higher level of customisation, a similar strategy should be designed for the bathroom as for the kitchen module. For the bathroom module, a standardised layout set should be created in order to minimise the impact of customisation features in the bathroom on the other modules, and within this standardised layout set multiple components should have customisation in their subcomponents. For example, the type of tiling should be customisable as should be the sanitary fitting. By keeping the layout of the bathroom module within a predefined choice set, the per house drawings process is simplified greatly and not dependent on the bathroom module. The components of the bathroom do have customisation features that can be adapted to the preferences of the consumer, and therefore, the achieved level of customisability and the positioning of the CODP for the consumer will increase to Tailored Customisation.

8.2 Supply chain effects

From the test for alignment, it was seen that every product module at CascoTotaal should be improved from the consumer perspective. The amount of improvement needed was also determined during the gap analysis where it was seen that, the amount of feasible and preferred improvement is different for every product module. Therefore, the effects on the supply chain are also different. In this section, the supply chain effects of realizing the preferred improvement of the CODP positioning are described. The effects are described based on two factors. The first factor is the effects on the process itself within CascoTotaal and its suppliers. The second factor is the logistical component required to achieve the change in CODP positioning determined in the gap analysis.

8.2.1 Process effects

During the gap analysis, the goal was to find the most feasible changes to the product module in order to achieve the required CODP. The limitations analysis was used to determine if changes were possible, however, the impact on the process of these changes was not determined. In this section, the impact on the process of CascoTotaal are determined and the required changes to the and information flow and process configuration are further explored.

8.2.1.a Structural work

The impact on the process of CascoTotaal by offering more customisation features in the structural work based on the gap analysis will result mostly in an increase in the installation materials component (placement of sockets and switches and the placement of telecommunication lines).

In the BPMN model, the installation materials CODP is located in the preparation of the casting when the positioning of the physical installation materials is linked to the specific consumer via the per house drawings. This is the point in the model where the information stream from the consumer is linked to the physical product. This point is moved backwards in the stream since, in the old positioning, the CODP was located in the final step of the stream, the acceptance of the house. The consumer accepted the product as it was since there was no customisation possible for the Structural work module.

By repositioning the CODP to the step “Prepare casting”, the process for the Structural work module will become more critical to the entire process since it now requires specific consumer information in order to assemble the module to order. With this classification of assemble-to-order process, it can also be seen that the required level of Customised Standardisation is achieved.

The per house construction drawings were already consumer specific for other modules, but the structural work module was not dependent on these. Now that the placement of the installation materials is also dependent on the "Per house construction drawings" the information process from consumer to customer has become more critical overall.
In the current information flow model, as seen in the BPMN model, the customisation features preferred by the consumer are transferred to the customer, the customer then transfers these features to the main contractor who has to incorporate them into the per house construction requirements. These requirements are then the input for the Per house construction drawings constructed by the office of CascoTotaal, until they are finally used by the structural work factory to construct the product.
At every stakeholder in the information flow there is the risk of information mistakes or delays in the information transfer, and since the structural work is one of the most critical modules in the final product, mistakes in information can and will disrupt the entire process planning and execution for the rest of the modules.

8.2.1.b Interior layout

Since the components of the interior layout module are all locally stocked products as can be seen in the SCOR thread diagram, the flow of materials and the way of construction in the process are not impacted. A change in layout of the interior walls does not impact the construction work in the process of CascoTotaal since the interior layout is constructed on a separate interior station on the construction line. However, the amount of work to be performed on that station can vary. This will introduce more variation in manpower needed.
Besides the physical impact, the process information flow for the interior layout is greatly impacted when the BPMN model is analysed for the change in CODP. The current positioning of the CODP in the BPMN for the interior layout is at the final stage of the customer accepting the house from the consumer since the current customisation level is Pure Standardisation and the consumer is not involved in the interior layout decisions. In the new situation, the preferences of the consumer with regards to the interior layout are expressed to the customer who will translate these into the specifications towards the main contractor. The main contractor will incorporate these into the requirements per house and the office of CascoTotaal will translate these requirements into per house drawings. These per house drawings are then communicated back to the main contractor who will install the interior walls themselves or communicate the drawings towards the sub-contractor who will install the interior walls. This is the point where the information flow from the customer will be coupled to the physical material flow and specific unit. The new CODP will now be the production of the house by the main contractor or the conducting of a subcontracting job. However, the information flow is not optimised for this positioning.
From the BPMN model it can be seen that because the positioning of the consumer CODP is now changed and the preferences of the consumer can change for every house, the per house requirements and construction drawings will change for every house bringing a lot more engineering work for the office of CascoTotaal. This engineering will not only be generated by the interior layout changing per house, but also because other modules such as the technical systems are dependent on the interior layout. The technical systems for example are located inside the interior layout walls. This proves that the information flow of the interior walls is crucial for the rest of the process. A weak link of the repositioning of the CODP for the consumer is therefore, that if there is miscommunication or communication delay between any stakeholder, the whole process can be disrupted.

8.2.1.c Technical systems

The current positioning of the Technical systems module CODP for the consumer in the process of CascoTotaal has multiple locations for the different components. In the current process, as seen in the current situation analysis the Water- and Ventilation systems are pure Standardisation components. The only customisation features for the consumer is located in the type of Heating system and the incorporation of solar power in the Electrical system. Therefore, in order to incorporate a predefined set of customisations proposed in the gap analysis, the CODP for the consumer needs to shift. This shift will not directly happen in the physical products used, since the current range of products that can be incorporated is sufficient to generate multiple customisation sets. The impact on the process itself will also be minimised if pre-engineered sets of features are included and the assembly of the module, even though there will be more change in the products and number of products used per house, the work can still be performed at the same location in the factory since the Technical systems module has a separate station in the Finishing factory. By offering the customisation as predefined sets, the station in the factory can better plan, and for every set offered, the most optimal way of installing them can be engineered before the construction work starts on the house, minimising the process impact.

However, there is a large shift in the positioning of the CODP when the information flow is analysed in the BPMN model. In the current situation, the consumer preference is incorporated in the final product by the sub-contractor responsible for the technical systems. The preferences expressed by the consumer are transferred to the customer and incorporated in the per house requirements by the main-contractor. The main contractor then transfers the information towards CascoTotaal who will incorporate them into the per house construction drawings. These drawings are than communicated to the main-contractor who will communicate them to the sub-contractor responsible for the technical systems. The point where the physical flow is linked to the specific consumer (CODP) is therefore located at the conducting of the subcontracting job. However, this flow as described is not for all the components. The pure standardisation components without any customisation features are all standard and are only linked to the consumer at the acceptance of the house by the consumer from the customer.

With the introduction of more customisation in the technical systems through the predefined sets on the component level, the flow of information will not directly be impacted. The location of the CODP at the conducting of the subcontracting job will now be the location of the CODP for the entire product module in order to achieve the required customisation level of Customised Standardisation.

8.2.1.d Interior finish

For the interior finish module, the impact on the process of CascoTotaal is not limited to the way the information flow is organised or the positioning of the point in the process where the information for the consumer is linked to a specific process step like in the previous modules. For the interior finish, the process step in the physical process where this linking of product and consumer should happen is non-existent in the current process of CascoTotaal. So, in order to be able to incorporate customisation in the interior layout on the most feasible level, a new step should be added to the production line in the finishing factory of CascoTotaal.

However, there are a fixed number of ten positions or stations possible in the finishing factory per production line. Also, the interior finish is dependent on other modules being finished before it can be installed in the final unit. For example, the structural work is the most critical

since all the other modules are fitted to it as seen previously. Also, the interior layout should be completed and the technical systems should be installed in the outer and inner walls.
The interior finish therefore needs to be incorporated in the production line after the structural work, interior layout and technical systems are complete. But, it can be installed before the kitchen and bathroom modules are installed in the final unit. Also, the interior finish is not dependent on the exterior finish since work can be done on the in- and outside of the unit at the same time on the same station in the production line.
Besides the location in the production line, the time needed for the completion of the module will differ when multiple customisation options are offered to the consumer. For example, when tiling is applied, the tiles should be installed and fully dried, which takes a full day or production step. After this a second day is used for the grouting of the tiles. So, tiling takes up two production steps. If wallpaper is chosen for the wall finish for example, only one production step is needed. These changes in time needed to complete the interior finish module can introduce inefficiencies in the total process.
Besides the different timings of sub-components, different sub-contractors are needed for specialised finishes. This will make the planning of the process more difficult for the main contractor and can impact the price of the final product while introducing multiple disruptions in the process when information is not transferred smoothly.
For the information to be transferred from the consumer to the final product, the consumer first expresses their preferences for the interior finish to the customer, the customer transferred the preferences for all the houses in the order quantity to the main contractor. The main contractor then sets up the per house construction requirements incorporating the preferences for every consumer to the houses. The per house construction requirements are then communicated to CascoTotaal to be incorporated in the per house drawings. However, not all the preferences are incorporated in the drawings, only the finishes that can influence the construction like the dimensions of the chosen tiling to engineer the outlet positions on and the interior wall dimensions. The rest of the preferences for the interior finish is directly communicated to the sub-contractor who needs to apply the finish in the final unit. Also, the main contractor should incorporate the preferences in the schedule of the finishing work in order to assign the right sub-contractor at the right time to the right unit. With this complex information flow, it can be seen that incorporating the interior finish as a Tailored Customisation will have multiple CODPs depending on the chosen sub-components by the consumer.

8.2.1.e Exterior finish

In order to incorporate consumer choice in the exterior finish module, the decision-making points needs to change from the customer to the consumer for some of the decisions made on the component level. As seen in the placement of the CODP in the current situation, at the moment all of the decisions regarding the exterior finish are made by the customer. As seen in the limitations analysis, it is not preferable to incorporate the preference of the consumer in the insulation component since the impact on the entire process would be to large since changing the insulation type or value, the entire design of the house will change. A higher insulation value will change the maximum dimensions and also the type of insulation can have a significant impact on the rest of the fitted modules and components.
However, in order to achieve the most feasible CODP positioning for the consumer, more customisation is required in the module. This customisation can be a subset of the options available for the customer. The options that the customer transferred to the consumer should

be determined per order in consultation with CascoTotaal to achieve the required CODP positioning of Customised Standardisation while still complying to the main design of the customer. In order to achieve this, the information flow between CascoTotaal, the customer and the consumer should be optimised.
In the current situation, the CODP for the consumer in the BPMN model is located in the acceptance of the house by the consumer from the customer. When customisation features are offered to the consumer this location will change. The required information is transferred between the consumer and the customer when the consumer chooses the options. The customer collects all the required options of the entire order (all houses being built in a certain production series) and transfers this to the main-contractor. The main contractor will then transform the information into per house construction requirements and these will be transferred to CascoTotaal. CascoTotaal will than make the per house construction drawings which are distributed back to the main-contractor who will distribute them to the assigned sub-contractor. The sub-contractor will use the information to conduct the sub-contracting job as required. This is the point in the process where the new CODP for the consumer will be located.
As seen in the BPMN, the information meets the physical flow at the sub-contractor level. However, the subcontractor is not the same company for every component and even type of sub-component installed during the assembly of the exterior finish. Therefore, a significant process impact of offering customisation in the exterior finishing module will be the number of sub-contractors involved in the process. This can be compared to the situation of the interior finish. Like the interior finish, different sub-components of the exterior finish can also have different lead times in the process. For example, when brick slips are used, two steps are needed after the installation of the insulation. First the brick slips need to be glued to the insulation, and then one day later they need to be grouted. When artificial wood panels are used, this grouting step is not needed and the process is shortened by one whole day. This requires a tighter planning from the main-contractor and tighter process control if the customisation level is increased to the most feasible Customised Standardisation.

8.2.1.f Kitchen

During the gap analysis, it has been seen that the current customisation level of Customised Standardisation for the consumer is not sufficient to maximise the consumer satisfaction. The customisation level offered to the customer however is sufficient at the level of Tailored Customisation. During the limitations analysis, it was seen that because the kitchen is produced at a different factory and only assembled from sub-assemblies at the finishing factory of CascoTotaal, a higher level of customisation would not directly impact the process of CascoTotaal. A side note to this is the interdependency to other modules such as the location of the technical systems should be predefined in the design. Therefore, Pure Customisation was not desirable. The subcomponents for the; Appliances, Cabinets and Countertops are all constructed at the kitchen supplier while the Tiling component is installed as part of the interior finish module by the same sub-contractor who installs the rest of the tiling throughout the final unit.
By analysing the SCOR thread diagram (Appendix III) for the kitchen supplier, it can be seen that on the component level of the kitchen there is already a make-to-order production step present. Also, the sub-components used for the construction of the kitchen at the moment are a mix of stocked and made-to-order products. This means that there is already a CODP present at the kitchen supplier placing the current kitchen at assembled-to-order.

In order to further increase the customisation level, more customisation features should be incorporated in the assembled-to-order strategy of the kitchen supplier. For this, the information flows from the customer towards the final unit in which the chosen options will be installed will have to be aligned. Seen in the BPMN model, in the current situation, the kitchen is chosen at the, by customer appointed, kitchen supplier and the chosen options are transferred by the customer to the main contractor. The main contractor incorporates the kitchen components in the per house requirements to be transformed into per house construction drawings by the office of CascoTotaal. The per house construction drawings are then communicated back to the main-contractor who distributes the drawings to the sub-contractors responsible for the installation of the components within the unit. In the current process, this is where the products are linked to a specific consumer (at the sub-contracting job or the production of the house by the main contractor, deepening on who is responsible for which component).
In the new situation of customisability by the consumer, the steps will not change and the CODP will stay in the same position. However, the amount of information exchanged is greater and the verity of products to be installed as part of the kitchen module are greater. Therefore, the information flow has become more critical as it was before.
In the process of CascoTotaal it is now seen that the greatest impact on the entire process is the shift of the decision-making point. In the current process, the customer is the decider for most of the components and sub-components to be used. Even when there are choice options for the consumer, the customer still decides what those options are and limits them significantly in order to simplify the whole process. In the new situation, in order to increase the customisation level to Tailored Customisation, most of the decision are now placed at the consumer. Therefore, the verity in the process increases significantly. However, the physical process steps and information process steps do not change but, the amount of information increases together with the verity in physical products to be installed.

8.2.1.g Bathroom

As proposed during the gap analysis, in order to minimise the process impact while still achieving the most feasible level of customisation, the impact on the process of every component should be analysed very carefully. In the relative impact analysis, it is seen that the line of the relative process impact is above the line of the relative consumer satisfaction. This does not mean that it is not viable to incorporate more customisation options in the bathroom as can be seen in the average importance of the bathroom. The bathroom is the third highest module and therefore, consumers can be satisfied above average by offering customisation features. However, incorporating these features can have larger impacts on the process. For this reason, the layout of the bathroom has to be offered in a standardised pre-engineered set of choices. In this way, customisation is offered, but the impact on process with regards to the per house drawings is minimised since the consumer can only choose between known possibilities. Within this layout, the technical systems component should also be incorporated since this impacts the module of the technical systems also and by incorporating it in a standardised set, the impact on the process of the other module can be reduced.
For the bathroom module, analysing the SCOR thread diagram (Appendix III) shows that there already exists a make-to-order step in the bathroom manufacturer where all the components are produced according to the preferences of the consumer if these are transferred through the information process. In the BPMN (Appendix IV) this information process can be traced

to find the current positioning of the CODP. When this is done, it can be seen that the route of information is very similar to that of the kitchen module. The consumer first expresses their preferences to the customer who will collect the preferences of all their consumers and transfers these to the main-contractor to be transformed into per house construction requirements. These requirements are then transferred to the office of CascoTotaal where they are included in the per house construction drawings. These drawings are then distributed back to the main-contractor who will distribute them to the sub-contractor responsible for the construction of the bathroom in the finishing factory. Meanwhile, the finishing factory of CascoTotaal will order the required components with the chosen sub-components from the bathroom supplier to be delivered to the finishing factory. The CODP for the bathroom at the moment in the thread diagram is located at the bathroom supplier while the CODP in the BPMN is at the subcontracting job in the finishing work factory of CascoTotaal. Just like at the kitchen module, the positioning of these points is not changing when the customisation levels increase. However, the decision-making point is changing form the sub-component level from the customer to the consumer for the components; Sanitary fittings, Tiling Cabinets and Accessories. In these modules, the customer has to transfer more decisions and possibilities for customisation to the consumer in order to achieve the most feasible level of Tailored Customisation.

8.2.2 Process effects conclusions

Now that the process effect of all the modules have been described separately, conclusions can be drawn about the impact of consumer preference on the process of CascoTotaal in general. As seen in the separate modules, due to the limitations analysis proving that for most of the modules there are very limited limitations to implementing consumer choice, the process impact to the physical process of CascoTotaal are very limited. However, it was also seen that in order to achieve the most feasible positioning of the CODPs, all modules need to increase the level of customisation possible.

In order to achieve these levels of customisation, for almost all the modules except for the Kitchen and Bathroom module, this means that the point where the information flow is linked to the physical product has been moved further inside of the process. This means that more information is required from the consumer about their specific preferences in order to start the process and the construction of the consumer specific house. However, even though there is more information required in the separate modules, most of the required information from all these modules follows the same path through the BPMN and have the same starting and ending points in the information flow (Figure 54). Therefore, information streamlining and the removal of unnecessary information transfers between stakeholders can have a large impact on the entire process and the chances of information faults.

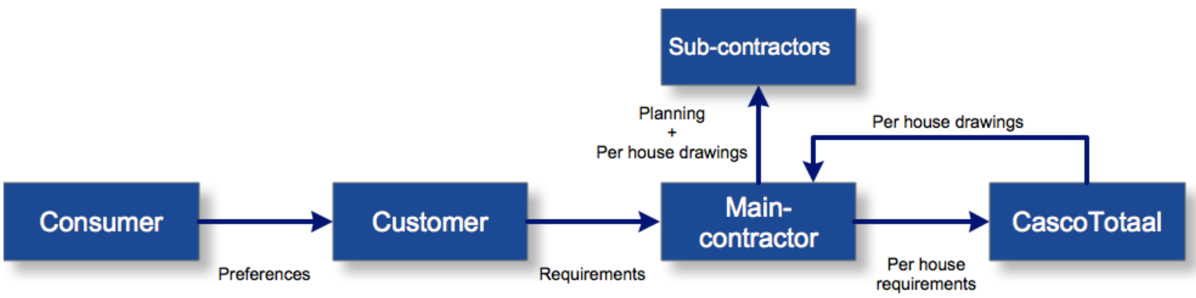

Figure 54: Current information flow for CascoTotaal

As depicted in Figure 54, the bundling of information results in a very concentrated flow of information, but the flow is still following the path through all the stakeholders. Therefore, the transfer of information from consumer to customer and from customer to main contractor and even the transfer from the main contractor to CascoTotaal can disrupt the information flow and thereby disrupting the entire process. The information links are present in all the product modules and therefore are very critical links in the information flow which are at the moment not efficiently constructed as seen in the process impact of each separate module before.
Besides the impact on the information flow there are also other factors impacting the process of CascoTotaal with the introduction of consumer choice in the separate modules, most of these changes are module specific and can be overcome by specifying the amount of change possible for the consumer while still keeping the required level of customisation, and even though as seen in the process effects most of the process impacts are in the information flow, the logistics between the supplier and the finishing works factory will also be impacted by the offering of customisation features in the separate modules. These logistical effects are not directly impacting the running of the process as was analysed in this section, but are an integral part of the whole industrialised housing supply chain as seen in the SCOR thread diagram. So, in order to fully capture the effects on the industrialised housing construction supply chain when consumer preferences are incorporated, these effects on the logistics also needs to be examined.

8.2.3 Logistical effects

In this section, the logistical effects are explained based on a detailed analysis found in Appendix VI in order to find the full impact on the supply chain. In order to examine the logistical effects of CascoTotaal, the shift in general supply chain model as described by (Bowersox, Closs, & Cooper, 2002) will first be examined for every product module since it describes where in the supply chain the logistical impact is the greatest. (Bowersox et al., 2002) generalised the basic supply chain as one of two models: Anticipatory (trying to predict the market and produce accordingly) or Responsive (only produce what has been ordered).

Anticipatory model

The anticipatory model is driven by consumer demand forecasting (Figure 55). Through the forecasting of consumer demand, materials and components are purchased and products are manufactured. After manufacturing warehousing is used in order to create a buffer between the forecasted and actual demand of the market.

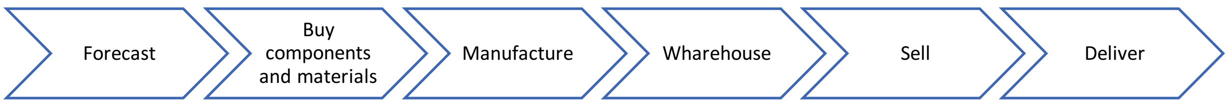

Figure 55: Anticipatory business model (Bowersox et al., 2002)

In the anticipatory supply chain logistical model, the forecast is leading and if the forecast is not accurate enough, the company risks lost sales due to stock outs or inventory. With the forecast as the most important driver for the logistical process, the likelihood of misgauging the market will increase. However, for non-critical components, forecasting demand and purchasing components and materials can be time saving in the total process. Therefore, an analysis is made which components and sub-components can be purchased based on forecasting in order to decrease the process risk of stock-outs.

Responsive model
In the responsive model (Figure 56), the process is initiated by a sale after which materials are purchased and a customer or consumer specific product is manufactured and delivered directly to that customer or consumer. The responsive model can be compared to the make-to-order production strategy where the differences between the made-to-order and the responsive model are the execution time and the level of mass customisation (Bowersox et al., 2002).

Figure 56: Response-based business model (Bowersox et al., 2002)

The advantages of the responsive model compared to the anticipatory model are the elimination of inventory in the warehousing between manufacturing and sales/delivery since all the products that are produced have already been sold. However, the information flow needed to ensure a quick process from sale to delivery is far more critical for the responsive model since all the information about the product requirements have to be known before the process can start. But, the main difference between the anticipatory and responsive supply chain model is the effect of timing. In the responsive model, the forecast element is eliminated and therefore, the total supply chain relies more on joint planning and fluent information exchange between the stakeholders within the total supply chain. This will also increase the effect of the logistical impact since the logistical component within the total supply chain will be more time critical as would be in the anticipatory model where the time component of the logistics can be included in the forecast.

For the general logistical model used at CascoTotaal, it is seen that there is a combination between the anticipatory model and reactive model. the logistical model that is used per product module or even per component of the product module is mainly influenced by the ability to forecast the demand of the components or sub-components needed. With regards to the ability to forecast demand it is seen that in almost every product module the introduction of more customisation features decreases the ability to forecast. As seen in the gap analysis, the level of customisation has to increase for every product module in order to achieve the required level of customisation and move the CODPs to the most feasible positioning. It was seen that when more customisation features were added to the product modules, more fluctuations in demand were introduced when compared to the current situation. These fluctuations are created because more sub-components are added and the decision-making point is transferred from the customer to the consumer. This means that the point where the actual demand is known shifts further forward in the process and this in turn will create more uncertainty in the forecast. Besides this, more customisation for the consumer increases the fluctuation since more spread in sub-components is possible. The result of this is that more product components are changing from an anticipatory logistical model to a reactive model. This results in the information flow becoming even more critical as it already was as seen in the process effect. Since the needed components are now not forecasted but ordered once the final design is known. This means that the reaction time of the total logistical system is more critical. Also, the ability to deliver the right sub-components at the right time just before they are needed at the finishing factory has become more critical as the number of sub-components increases for almost all the product modules.

In order to find the critical impact on the logistics within the supply chain of CascoTotaal besides the basic logistical model, three most common subcomponents of logistics; Inventory, Transportation and Location (Vidalakis, Tookey, & Sommerville, 2011) will also be further analysed. Below, a further explanation per subcomponent is given:

8.2.3.a Inventory

On the traditional construction site, contractors have limited to no inventory possibilities on the construction site itself. Also, the traditional construction site inventory is often out in the open and loss of inventory due to weather influences and criminal activity is therefore not uncommon. The resulting inefficiencies that are the result of this such as; backlogs, capacity mismatches and unavailability of materials are influencing the performance of the entire process (Vidalakis et al., 2011).

In the finishing factory of CascoTotaal, every contractor gets their own inventory position. However, these positions are limited and non-value adding inventory should be avoided at all times. Therefore, efficient inventory planning is needed. But, by increasing the amount of customisation possibilities per product module, the amount of inventory planning required to keep the process running can change significantly.

For most modules, this is not a direct problem since the amount of sub-components needed does not increase directly, only the number of possible sub-components to be installed does. But, for the interior layout the difference between the number of sub-components needed in the current process and new process is significantly more, the required storage space at the finishing factory may not be sufficient. And more replenishing moments are needed between the first-tier supplier and the finishing factory inventory. Also, during the inventory analysis it was seen that for almost all the product modules, the inventory at the finishing factory was not sufficient to cope with the fluctuations in demand on the long-term. Therefore, a long-term relationship is needed between the first-tier supplier and the finishing factory in order to optimise the logistical process and optimise the replenishing moments for the limited local inventory at the finishing factory from a larger inventory at the first-tier supplier. In the current process, Bouwcenter Logus De Hoop is used for this as they are the preferred supplier and part of the same parent company as CascoTotaal. By using the inventory of Boucenter Logus De Hoop, the fluctuations in demand can be equalised over time since their inventory is not only used to supply CascoTotaal but also other housing construction companies. It is seen in the logistical analysis that Bouwcenter Logus De Hoop is the preferred supplier and that almost all the needed materials are sourced from them. This means that there is the possibility for a long-term relationship to be built between CascoTotaal and Bouwcenter Logus De Hoop. However, the creation of a long-term logistical relationship with one company can have advantages but also significant disadvantages for the entire process.

The positive effect of using a long-term relationship with a preferred first-tier supplier is mainly found in the repositioning of the logistical control. In the current process, Bouwcenter Logus De Hoop and CascoTotaal communicate the process planning and materials needed by the finishing factory, Bouwcenter Logus De Hoop is then responsible for the further logistical planning and communication with all the second-tier materials suppliers in order to run the logistical process. The responsibilities of the finishing factory are now reduced to the local inventory control and keeping track of the replenishing schedule of the first-tier materials suppliers (mainly Bouwcenter Logus De Hoop). And since most of the inventory is located at the first-tier material suppliers, the transportation factor of the logistical process it moved from the finishing factory to the first-tier supplier.

8.2.3.b Transportation

In traditional housing construction, the costs of transportation account for 10 to 20 percent of the total construction costs since the products transported are generally high volume and low value products (Vidalakis et al., 2011). Transportation costs are the most influential contribution to the logistical costs. In the off-site construction process like the one at CascoTotaal, increased demand for transportation due to the fluctuating demand of customisable features can create a situation where the increase in transportation costs does not come with proportional gains in income.

However, no separate transportation is taking place between all the second-tier material suppliers and the finishing factory, but the transportation is moved towards Bouwcenter Logus De hoop where it is coordinated into a single stream of materials flow towards the finishing factory of CascoTotaal with fixed replenishing transportation movements of the local inventory, usually once a week in the current situation. However, with the increase in customisation features this can increase in order to cope with the fluctuations in demand and the increase in sub-components needed for some of the modules like the interior finish. Another positive effect when compared to the traditional way of construction is that the bundling of multiple second-tier materials suppliers is happening outside of densely populated areas. Both the finishing factory and the warehouse of Bouwcenter Logus De Hoop are located on industrial complexes where the amount of hinder to surrounding people is minimised. Compared to the traditional logistical process of construction where all the separate materials are transported to the construction site in the middle of densely populated areas, this is a large improvement. And when more customisation is added to the process, more second-tier materials suppliers are involved so the effect of hinder decrease is even more pronounced.

However, the system of working with a preferred supplier who is responsible for almost the entire logistical process does have some negative effects on the process. The most obvious negative effect of relying on a very limited number of first-tier materials suppliers, and on one first-tier materials supplier for most of the product module components, is that there is a very strong reliability needed between the two companies. This can be found in the long-term relationship which has to be coordinated very well, and agreements about the responsibilities need to be made.

8.2.3.c Location

Traditionally, the production facility of the house (the construction site) is changing for every product produces (Vidalakis et al., 2011). In the past, this meant that the suppliers where local market providers for every product and location optimisation of the supplier's distribution centres was almost not possible. However, this will change if houses are constructed off-site in the factory of CascoTotaal. With this new off-site production, possibilities arise for long-term supply chain relationships between CascoTotaal and the suppliers. However, due to the introduction of customisation, the suppliers can be very divers due to the amount of customisation features offered and non-standardisation of the product.

This is partly overcome since both first-tier supplier and CascoTotaal are part of the same parent company, however, if the first-tier material supplier defaults or has a disagreement with one of the second-tier materials suppliers, the whole process will be disrupted since no alternatives are present in the logistical process. A second effect on the ability to optimise the logistical process and production process in general is the limited assortment of one single first-tier materials supplier. With the introduction of more customisation features per product

module and even components within the product modules, this limited assortment can become a bottleneck. If the assortment is not capable of increasing the amount of customisation features, or is not able to deliver the requested sub-components it is seen in the logistical effects that there are two options.
The first option is to switch to another first-tier materials supplier. But, this will reduce the ability to build a strong long-term relationship and increase the effects of transportation for the finishing factory decreasing the efficiency of the entire logistical process. The second option is to increase the assortment of the current first-tier materials supplier. As seen in the earlier, Bouwcenter Logus De Hoop is willing to expand their assortment if the order quantity is sufficient. Thereby showing that it is possible to increase the assortment of the current first-tier supplier. This means that the logistical process is able to be further optimised for the process of CascoTotaal, but that the negative effects of a single first-tier materials supplier have to be taken into account.

8.3 External effects

As described in the conceptual model, industrialised housing construction has two effects, one are the internal effects for the company performing the industrialised housing construction, and the other effect is seen in the surrounding world. These external effects do not directly impact the running of the internal processes, but do impact the market in which the products are sold. As described in the beginning of this chapter, closing the gap in the customisation level offered in the current situation towards the most feasible situation has besides the repositioning of the CODP also a second effect of market repositioning. In this section, this second effect and the reason for the potential market repositioning is discussed. The goal of the external effects analysis is not to calculate the exact effects of each proposed change to the process, the external effects matrix and market (re)positioning analysis are used to gain a general insight on the impact outside of the internal process when the positioning of the CODPs are changed for the product of CascoTotaal.

8.3.1 External effects matrix

The external effects mapping starts with the creation of an external effects matrix. The case study protocol gives the outline for the external effects matrix, the categories of the external effects measured (Construction time, Construction cost, Quality, Safety and Environment) are placed on the Y axis of the matrix while the product modules as defined in the product modularisation are placed on the X axis. The external effects matrix is now constructed by comparing the external effects defined during the current situation analysis to the possible future external effects extracted from the CODP repositioning during the creation of the most feasible positioning. Also, the supply chain effects are used to determine the exact effects by extracting them per product module from the process effects and the logistical effects (Table 11).

Table 11: Expanded external effects matrix

External effects	Product modules: Structural work	Interior Layout	Technical systems	Interior finish	Exterior finish	Kitchen	Bathroom
Construction time							
Off-site construction time							
On-site construction time							
Construction Costs							
Material costs							
Labour costs							
Logistical costs							
Quality							
Internal quality effects							
External quality effects							
Safety							
Process safety							
Product safety							
Environment							
Construction waste							
Resource consumption							

Construction time
In order to determine the external effects for the category construction time, the construction time is split into two components: on-site construction time and off-site construction time. Both on- and off-site construction time can be influenced for every module when the CODP is shifted. The effect on the construction time can both for on- and off-site be an increase or decrease for the specific module. When time increases (or decreases) for the off-site construction, the process time at the factory of CascoTotaal would be increased which can affect other processes, but, the effect of this is not visible on the final construction site of the house. When the construction time increases (or decreases) for the on-site construction, this does not mean the construction at the factory is impacted but the people living around the construction site are impacted more.

Construction cost
In order to determine the effects on the construction cost, they are divided into three separate components. The first component are the material costs, including all the costs of materials that are used in the product module. At the moment, the material costs account for 40% of the total construction costs. Besides the material costs the labour costs are the second component, include all the labour effects on the final construction costs per product module. The exact cost of labour is not discussed, but the effects on the total amount of labour is described. In the current process, the labour costs account for around 40% of the total construction costs. If more labour is required or more specialised labour is required due to the introduction of customisation features, these costs will increase. The last component of the construction costs are the logistical costs, include all the costs made for the logistical component of construction per product module. The logistical costs are not limited to the transportation of materials, but also include the costs of inventory per product module on both the inbound and outbound side. Currently, the logistical cost account for 20% of the total construction costs. If examined further it is seen that the outbound logistical costs accounts for 5% while the inbound logistical costs accounts for 15%.

Quality
In order to determine the effects on quality of the final, two categories are defined in the external effects matrix. These categories are the internal- and external quality effects. The internal quality effects include all the effects the shifting of the CODPs have per product module on the components and process steps that are executed internally. Internal quality effects can be process related or product related if the product is assembled inside of the process of CascoTotaal. The external quality effects include all effects on quality that are created outside of the process of CascoTotaal. External quality effects are the effects on quality that are not under the responsibility of process of CascoTotaal.

Safety
For the external effects on safety, two components are defined. The first component is the process safety and the second component are the effects on product safety. Process safety even though it also has an internal component is also counted as an external effect since the effects on process safety are also visible outside of the process of CascoTotaal. All impacts on the process safety created by the shifting of the CODPs in the product modules are counted as process safety. Product safety as it would suggest are all the effects of safety created by the CODPs shifting per product module on the safety of the product (the house).

Environment

In order to analyse the impact on the environment, the environmental impact is divided into two categories. The first category is the material waste produced during the construction of the house. The materials used during the construction of the house makes up for 50% of the environmental burden (Klunder, 2005) and is thereby the most important contribution to the environmental impact of housing construction. The second category to be analysed are the Resources used. The use of resources is a twofold component of the house. On the one side, resources apart from the materials are used to construct the house, as seen in the current external effects analysis previously in this report. The second factor of resource consumption is taking place once the house is handed over to the consumer. The average energy use of the house is changed with different positioning and options chosen by the consumer and therefore, energy use for both the construction process and lifespan after the handover to the consumer are analysed as part of the environmental impact.

8.3.1.a External effects for the process of CascoTotaal

Previously, the preliminary external effects found in the current situation analysis were used in order to expand the categories of the external effects matrix. In this section, these expanded categories are reflected on the process of CascoTotaal when the CODP shifts from the current positioning to the most feasible positioning. For this, a CascoTotaal specific external effects matrix is created in Table 12. A further explanation of the impact on the external effects categories is given below:

Table 12: External effects matrix for CascoTotaal

External effects	Product modules: Structural work	Interior Layout	Technical systems	Interior finish	Exterior finish	Kitchen	Bathroom
Construction time							
Off-site construction time		x	x	x	x	x	x
On-site construction time			x	x			
Construction Costs							
Material costs	x	x	x	x	x	x	x
Labour costs	x	x	x	x	x	x	x
Logistical costs			x	x	x		x
Quality							
Internal quality effects	x	x		x	x	x	x
External quality effects			x		x	x	x
Safety							
Process safety		x		x			x
Product safety			x				
Environment							
Construction waste		x		x			
Resource consumption			x		x		

Construction time

For the construction time effect at CascoTotaal it is seen that most of the effect is in the off-site construction time at the finishing factory. The only module not impacting the construction time is the Structural work module since the time to prepare the casting and cast the concrete is not effected by more customisation. Even though the technical installations will impact the module preparation, the time difference is negligible compared to the total preparation time required. For the rest of the modules, the introduction of more customisation features results in an increase in construction time at the factory. For most modules, a lack of repetition causes an increase in construction time since every unit can be different, setup times need to be added. The biggest impact on the off-site construction time is seen at the interior finish where a totally new step needs to be added to the construction process. This will add time to the off-site construction is it is chosen to perform the finishing of the inferior at the factory. But, offering more customisability will also increase the on-site construction time for the Technical systems and Interior finish components. For the technical systems, the on-site construction time will increase since added components will have to be connected together on the final location. An example of this are the solar panels, they are installed at the factory but need to be connected to the rest of the system on the final location. For the Interior finish, the on-site construction time will depend on where the finishing is chosen to be applied. If the consumer choses to let the units be fully finished, the on-site construction time will decrease compared to the current situation. But if the consumer choses to finish the units themselves, the on-site construction time will increase.

Construction cost

Due to the increased fluctuations in demand on the component level, the construction costs are also fluctuating. In the current situation, the components of the costs are known for the entire project, and therefore, the components per house are also known due to the high level of standardisation. However, with the introduction of customisation features in all modules, the materials needed per house can differ greatly, and the prices of the materials used can also differ greatly. Therefore, the materials costs for every module is subject to change and depending on the choices made by the consumer these changes will be positive or negative compared to the current situation. The same situation is seen for the labour costs. Since the amount of labour needed per house can fluctuate depending on the customisation features chosen by the consumer, the labour costs are also a result of the fluctuations in demand created by the increased customisability. An example of the cost fluctuations is found in the Structural work module where the consumer has the choice to incorporate floor heating. If this option is chosen, the materials costs will increase and more labour is required in order to install is thereby increasing the labour costs. The third costs factor, logistical costs, can be extracted from the logistical effects analysis. If more first- or second-tier material suppliers need to be involved, the logistical costs for the module are likely to increase. This is true for the; Technical systems, Interior finish Exterior finish and Bathroom module. These modules all require more components or sub-components from new suppliers increasing the logistical costs. However, even though the kitchen also requires more components, the current supplier has a sufficient assortment to cope with the growing choice. While the structural work and interior layout do not require new components to be added.

Quality

For the quality factor of the external effects, it is seen that all modules du have a quality effect when more customisation is introduced, however, the impact on the effects is not the same for every module. For all modules except for the Technical systems, the internal quality is impacted due to the increased fluctuations in product options. This causes a higher risk of defects during the construction of the separate modules or the wrong parts being fitted in the units. An example of this is the wrong placement of the interior walls or the higher complexity of the kitchen and bathrooms that are installed where repetition is eliminated due to the increased customisability. For the Technical systems, even though more choice is offered, the possibilities to choose from by the consumer are all pre-engineered which is comparable to the current process.
For the external quality, it is seen that the modules with relatively complex components and sub-components are impacted when more customisation features are introduced. For the kitchen and bathroom, the external quality is dictated by the quality of the components chosen. Lower quality sanitary fittings or appliances reduce the external quality, while brand name components typically increase the external quality. The same is true for the technical systems, but here the external quality is also impacted by the chance of defective products.

Safety
For the safety, it is seen that the only safety impact on the product level is in the technical systems where the safety of the final house is impacted by the components used that make up the chosen subset of options. If lower quality components are chosen, the positive effects are the costs, but the safety of these components can have a negative safety impact on the total products (house). However, the total safety effect is also determined by the process safety. For this it is seen that the reason why process safety is impacted is very different for the separate modules. For the Interior layout, the process safety is influenced by the layout chosen by the consumer. More confined spaces will decrease the process safety while more open rooms increase the safety since less work in the following modules has to be done in tight confined spaces. For the Interior finish, the step is not present in the current process and due to the maximum of ten positions on the production line, the interior finishing has to be combined with other construction work leading to more work being performed on a single position thereby decreasing the process safety effect. For the bathroom, a similar situation is seen as for the interior finish, however, the amount of specialised work increases and the bathroom is mostly a confined space. If more customisation features are added to the bathroom, the safety of the process risk may increase and thereby, the safety of the entire process decreases.

Environment
For the environmental impact of the CODP repositioning, both the Interior layout and the Interior finish can have an increase in material waste of the entire process. For the Interior finish, the waste is introduced since at the moment no interior finishing is applied. By incorporating the new step in the process, the waste it produces also needs to be added. For Interior layout however, the new “open” design can lead to more waste being produced. Since the interior walls are created using gypsum board, the ideal layout would always include full size boards. When the layout is open to customisation by the consumer, the consumer can create a layout that would result in walls not consisting of whole boards and thereby creating more construction waste. For the environmental impact of the consumed resources, a different situation is seen with two different effects. For the Technical systems, the chosen system is impacting the energy consumption of the house, and over the lifespan of the product, this can have an impact on the amount of resources consumed. However, for the Exterior finish, these resources are consumed during the construction of the house at the factory. When brick slips are chosen by the consumer for example, the step of grouting the wall will consume more materials and resources while artificial wood panels do not require the extra step. Thereby, the resources consumed during the construction are impacted.

8.3.2 Market repositioning
Besides the effects on the outside world described using the external effects matrix, the repositioning of the CODP also has an effect on the market positioning of the product. As seen in the beginning of this chapter, the market repositioning of the product is one of the two outcomes as seen in Figure 46. For this research, the first iteration of the described feedback loop for market repositioning will be explored. Based on the current process and stakeholders involved, the customers of CascoTotaal are all housing- associations or developers who buy the house and then rent it to the consumers. As described earlier, the main reason for this is that the products are not the single house, but have a minimum order quantity of 10 houses in order to ensure the continuity of the process. Therefore, it is not possible for the individual

consumer to buy a house directly from CascoTotaal at the moment. This could be possible in the future when the market repositioning makes it feasible for CascoTotaal to offer their products to individual consumers, but at the moment this is not feasible.
From interviews with the current customers it became clear that for the customers, the value of the product is the main focal point in the decision-making to build new houses. In The Netherlands, the value of a house is determined by a points system. In this system, housing components are scored, and the amount of points a house gets awarded in total determines the maximum allowable rent the housing association or developer can ask for that specific house (Huurcommissie, 2016) (Appendix VI).

8.3.2.a Base situation standardisation

In order to determine the market positioning based on the value determining points system, a base situation is first created for the Spero 1 single family home (Appendix VIII). In this base situation, a Spero 1 single family home is used in a standard configuration as would be the case in the first stages of the contract with the customer or contractor. This standard design is adjusted to the preferences of the consumer later in the process. The outcomes of the process effects and the logistical effects have been incorporated to standardise the needed features in order to keep the process feasible with regards to the impact and placement of the CODPs. The standardised features of the base situation are described below:

The dimensioning of the structural work

The dimensions of the structural work as seen in Appendix VIII create a usable interior square space of 87 m^2. This usable space is divided into two floors. On the ground floor level two structural units are used to create a usable floor space of 60 m^2. For the top floor one structural unit with a roof construction is used to create a usable floor space (minimum height to be counted as usable for a roof construction is 1,5m) of 27 m^2.

Positioning of bathroom and kitchen

As seen in the process effects, the positioning of the bathroom and kitchen are not left to the consumer since this would have a very large impact on the rest of the process but, the layout of both the bathroom and kitchen are customisable. For the positioning in the base situation, both the bathroom and kitchen are on the ground floor as seen in Appendix VIII.

Interior layout

For the interior layout, the interior walls that are part of the concrete structural work are also standardised on the ground floor. The rest of the interior layout walls depicted in the base situation of Appendix VIII are only there as a possible layout. The exact position of the interior layout is left to the consumer. However, for the points calculations, this base layout is used to get a comparison situation for different markets later in this chapter.

Exterior finish

For the exterior finish, the insulation of the house as discussed previously is not a customisation feature transferred to the consumer. Also, the exact finish of the house is not impacting the points granted to the quality of the house as seen in the previous section and the points calculation table of Appendix VI. Therefore, even though the exterior finish is a customisation feature for the consumer, it will not be used in the calculations of the market positioning.

8.3.2.b Calculation of market value for different configurations of the base situation

With the determination of the base situation Spero 1 single family house, the calculations for the possible market value of different configurations can be performed. Since the positioning of the CODPs per product module and the possibilities of customisation features have been determined previously, the value of the house can be calculated using the points system as described earlier. In order to find the value and market positioning of the base situation, two market sectors will be analysed in this section. First it is examined if the house can be configured to fit the requirements of the current social housing associations. Also, the possibilities for the private rent market sector are further examined.

Social housing market

In order for a house to be eligible for social housing in The Netherlands, the total number of points awarded to a newly build house cannot be above 145 (Rijksoverheid, 2017b). In Appendix IX Table 14, a basic configuration has been made and the points per category have been awarded for a house without any special customisation features added. A further description of the calculations is given below per category of awarded points:

All rooms in the layout are added together with the exclusion of technical spaces and hallways (hal, overloop), since these are not counted as living space. This results in 75m^2, and converting this with the table will result in 75 points being awarded to the living square space. Since these six rooms counted as living space are also heated, the total number of heated rooms is 6. All heated rooms are given 2 points, so the total amount of awarded points for heating is 12. The kitchen (keuken) and living room (woonkamer) are counted as separate heating areas as stated in the rules for "open kitchens" (Huurcommissie, 2016).

For the points awarded to the house for energy efficiency there are two possibilities. For the first possibility, the house is rented "as is" with no energy compensation agreement between the housing association and the tenant. The energy level of A++ will award the house the maximum amount of 44 points. However, if the technical systems module is configured so that the house is an energy neutral house (which is possible), an energy compensation agreement can be set up for the house between the housing association and the tenant. The tenant then pays an agreed fee for the energy use besides the rent (not to be translated into points) so the maximum payable rent will be lowered and the maximum number of points for energy efficiency will be 32. However, a extra per month fee has to be payed of maximally 1,40 euro per square meter (75*1,40 = 105 euro) for energy use and compensation of investments in the technical systems (Rijksoverheid, 2017a).

For the kitchen, the points awarded to the house are based on the length of the countertops. In the basic situation in Appendix VIII, the kitchen layout is the most basic design as would be acceptable for the social housing market. Also, the level of customisation is kept to a minimum possible within the most feasible positioning. No luxury features would be offered since these would result in more points being awarded. However, the minimal length of the countertop acceptable by todays standard as discussed in interviews with a housing association would be 2 meters. Therefore, the points awarded to the kitchen would be 7 in total. The customisation features are possible on the component level of the countertop finish, the cabinet finish and the tiling. This will still barely meet the required customisation.

For the bathroom, a similar situation is created as for the kitchen. The layout of the basic Spero 1 house as seen in Appendix VIII is used to determine the amount of points to be

awarded. The features in the bathroom can still be customised on the component level with regards to; tiling, sanitary fixtures and cabinets. However, no luxury sub-components will be offered as standard. In the minimal layout, the bathroom will include: one standard toilet, one standard washbasin and one standard shower. This will award the bathroom a total of 8 points.
With the interior of the house complete, the final category for points to be awarded on is the total property valuation. For this, the numbers are dependent on multiple factors that are unknown at the moment. One of these factors for example is the demand in the area and the ground value of the site the house is built on. However, in order to make an estimate of the points awarded for the property valuation, comparable houses in various locations are examined using the online tool of the Dutch government (Ministerie van Financiën, 2017). The resulting estimated property value (WOZ) is 130,000 euro. With this estimate, the points can be calculated as 130,000 divided by 8,259 resulting in 15,74 points and for the property value per square space it is calculated by dividing 130,000 by 75 and dividing this by 127 resulting in 13,65 points. These two values have to be added together and rounded to the nearest whole number resulting in a property valuation score of 29 points.

When all the points awarded for the separate sections are now added together, the total amount of points results in: 175 points when no agreement is made regarding the energy efficiency and 163 points when there is an agreement made about the energy compensation. This means that in the current composition the Spero 1 single family house is above the maximum of 146 points to be eligible as a social rent house. However, when the layout is adjusted so that less square space is counted as living space and storage space is added to the floorplan or the valuation of the property being lower in areas of less demand, the Spero 1 single family house can be brought to the maximum of 146 point to be repositioned in the social housing market. However, this would require a second iteration of the CODPs repositioning as described in the beginning of this paragraph and the introduction of customisation features as proposed in this research is no longer feasible.

Private housing market

since the points social housing configuration is above the maximum of 146 points, the house as configured would automatically be counted as a private sector house. Since for the private sector there is no maximum amount of points, a house can have the configuration as seen in Appendix VIII with added customisation features. In this section, multiple configurations of the Spero 1 single family house are made and compared in order to find the best suitable market positioning spread. Four configurations based on the basic design of Appendix VIII are made in two categories. In the first category, a minimal and a maximum configuration of a non-energy neutral house are made, while in the second category, a minimal and a maximum configuration of an energy neutral house with the appropriate energy compensation agreement between customer and consumer are made.

Non-energy neutral Spero 1 house

For the non-energy neutral version of the Spero 1 single family house, two compositions of the house are made (Appendix IX Table 15). The first composition will include the minimal needs with regards to consumer customisation. The second composition is a fully maximally customised house with the highest level of luxury chosen for all the customisation features.

These two extreme placements of the CODPs are chosen to get the possible spread in market price while all possible placements in between also satisfy the consumer.
When the points are now calculated for both compositions, it is seen that some features do overlap where customisation does not make a difference. This can be seen in the square space of the house for example. Even though the layout of the house is open to customisation, the maximum available square liveable space will stay the same at 75 m^2 awarding both compositions 75 points. The same is true for the energy efficiency, even though the technical systems of the house can be customised in different ways of heating or ventilation packages, the energy efficiency level will always be A++ and therefore, both compositions get awarded 44 points. Also, the property valuation estimate will stay the same for both houses. Even if the customisation of the house would change the valuation number. For new private sector houses, the valuation points are always a minimum of 40 points and since the actual points calculated are always far below this minimum these will be awarded to both compositions. Besides the common awarded points between the two compositions, customisation will have an effect on the points awarded to; heating, kitchen and bathroom.
For the heating, customisation in the technical systems can exclude the non-liveable square spaces (hal, overloop) from heating. This will result in a two points difference between the two compositions with the minimum being 12 and the maximum being 14 points for the heating system. Also, the customisation features on the sub-component level in the kitchen can make a difference. When more luxury features are chosen in the kitchen like a build-in dishwasher or luxury countertops, the points awarded to the kitchen can double between the minimum and maximum compositions, resulting in 7 points for the minimum- and 14 points for the maximum luxury version. The last housing component where customisation can play a role is the bathroom. In the bathroom, it is seen that the customisation of a set of layouts can make a difference besides the level of luxury in the sub-components. When the two compositions are compared, it is seen that in the maximum, a different layout is chosen with two washbasins and a bathtub/shower combination. This will result in a difference of 4 points with 8 points for the minimum- and 12 points for the maximum composition. Besides this, the sub-component level can make a further difference when luxury sanitary fittings or accessories are added, the maximum composition can be doubled to 24 points in total.
By now comparing the two compositions it is seen that the minimum composition will result in a total amount of 186 points while the maximum composition will result in a total amount of 211 points. When these numbers are transformed into maximum rents the customer can ask from the consumer using Appendix VI, this will result in 927,56 euro for the minimum composition and 1057,18 euro for the maximum composition.

Energy neutral Spero 1 house
Like the non-energy neutral Spero 1 house, for the energy neutral Spero 1 house two compositions are made in Appendix IX Table 16. Since the basic house is the same, most of the offered features result in the same points being awarded to the housing components therefore, the features are not all recalculated again in this section. But, since there can be a difference in the amount of points awarded to the house when there is an energy compensation agreement made before the contract signing between the consumer and customer, this is further elaborated in this section. When the consumer and customer agree on an energy compensation amount for the energy neutral house, no energy efficiency points are counted but instead a compensation value of 32 points is counted which will lower the amount of rent the consumer has to pay each month. On top of the rent, the consumer will

have to pay the energy compensation for the investments needed to become energy neutral to the customer.
For the Spero 1 single family house this will result in the following points being awarded to the two compositions as seen in Appendix IX Table 16: 174 points for the minimal composition and 199 for the maximal composition. For the amount of rent the consumer has to pay this means that in the minimal composition will be 865,31 euro per month, a difference of 62,25 euro per month. For the maximum composition, the rent lowers to 994,95 euro per month, a difference of 62,23 euro per month. However, the consumer will also need to pay the extra energy compensation besides the normal rent. This energy compensation has to be determined between consumer and customer in a separate contract and is set at a maximum of 1,40 euro per month per square meter of liveable floor space (Rijksoverheid, 2017a). For the Spero 1 single family house this will result in a maximum energy compensation of (1,40*75) 105 euro per month added to the maximum rent calculated.

8.3.2.c Market positioning of the Spero 1 single family house

Now that the first iteration of the market positioning has been calculated, the market positioning can be examined. The market positioning reflects the position in the market that the Spero 1 single family house would have in the current market with the CODPs positioned as determined in the most feasible CODP positioning earlier in this report. The product positioning of the Spero 1 in the housing market will be based on the product value points calculations, the results of these calculations are summarized in Table 13.

Table 13: Spero 1 single family house value calculations results

	Non-energy neutral Minimum composition	Non-energy neutral Maximum composition	Energy neutral Minimum composition	Energy neutral Maximum composition
Awarded points	**186**	**211**	**174**	**199**
Maximum rent	€927,56	€1057,18	€865,31	€994,95
Energy compensation	-	-	€105	€105
Total monthly cost	**€927,56**	**€1057,18**	**€970,13**	**€1099,95**

When looking at the results of the previous product value calculations it is seen that the energy neutral houses are more expensive per month when the energy compensation is taken into the monthly payments. However, a side note to this is needed because for the non-energy neutral versions of the Spero 1, the energy consumption is calculated based on the actual energy use of the consumer and is charged by the customer on top of the monthly rent. Therefore, the actual monthly costs can be higher depending on the energy consumption of the consumer. However, for this market positioning, the value of the house that determines the market positioning is the value without energy consumption or energy compensation. This is done because the Dutch government also categorized houses for rent based on their base rent price without energy consumption or compensation.
In order to now determine the best suitable market for the Spero 1 single family house, the maximum amount of rent the customer can ask from the consumer will be the determining factor. At the moment, the Spero 1 single family house has a base price spread (without energy consumption or compensation) between 865,31 euro and 1057,18 euro per month. With this price spread, the Spero 1 house can be placed in the mid-priced segmentation of

the Dutch private rent housing market of 700 to 1000 euro per month excluding service charges (VGM NL & NVN, 2017).

At the moment, the private rent market is getting a lot of attention form the Dutch government. Especially the mid-priced private rent housing market just above the social limit of 146 point or 710 euro to 1000 euro is getting a lot of attention from the Dutch government in order to stimulate the flow through of tenants from the social housing market towards a higher class house (Vlak, van Middelkoop, Schilder, & Eskinasi, 2017). The Dutch government is at the moment looking for ways to stimulate the construction of more mid-priced private rent market houses by housing associations and developers since at the moment, the number of available houses in this market sector is below the needed amount for a healthy flow through of tenants from social housing towards higher level housing (van Lith, 2016).

CascoTotaal can use the government stimulation of this government stimulation for the market positioning of the Spero 1 single family together with the benefits of the entire off-site construction concept to gain an advantage on the competition.

The houses CascoTotaal build have various advantages for the customer which can be exploited when the Spero 1 house is positioned in the private rent mid-priced market. The price level of the Spero 1 as seen in the previous calculations are within the medium to high range of the market sector mid-priced private rent houses. But, the advantages of being able to incorporate consumer preference in the house can be value increasing to the consumer and the advantages of the CascoTotaal concept of housing construction can be an advantage to the customer. When the average prices for private rent houses are compared per square meter of living space, it is seen that when the houses are built as they are in the current process (no interior finish), the price of the house cannot be justified.

The average price per square meter for private rented single family houses at the moment is 8,37 euro per month per square meter of living space (VGM NL & NVN, 2017). For the Spero 1 this would mean a price of 627,75 euro per month when calculated for 75 m^2. When this is compared to the new proposed most feasible level of customization (including interior finishing) the price per square meter increases to 15,13 euro per square meter of living space (VGM NL & NVN, 2017). For the Spero 1 this would translate to an average price of 1134,75 euro per month based on the 75 m^2. Now it is seen that by incorporating more customization features up to the level of the most feasible positioning of the CODPs the price level of the Spero 1 house compositions as previously calculated is conform the market average. It can be concluded that when interior finishing is incorporated and the most feasible levels of the CODPs are also incorporated in the Spero 1 house, the price per month for even the most luxurious configuration is below the market average. Therefore, the market positioning of the Spero 1 house in the by the government stimulated mid-price private rent housing market is the most feasible positioning based on this first iteration of the CODP placement and process optimization. However, further research on later iterations of the incorporation of consumer preferences and the exact repositioning based on the most feasible CODPs is recommended since, as discussed in the beginning of this chapter, only the first iteration is calculated as part of this report.

PART C – Research results

9 Conclusions

With the effects on the supply chain and the external effects discussed in the previous sections of this report, all the areas of the conceptual framework have been analysed. This chapter will now conclude the entire report by answering to the sub-questions formulated in chapter 2 in order to be able to answer the main research question of this report.

9.1 Answering of the Sub-questions

In order to answer the main research question, seven sub-questions have been formulated at the beginning of this report. In this section, an answer will be formulated for these seven sub-questions based on the results of the case study performed at CascoTotaal according to the case study design and accompanying case study protocol of described in chapter 4.

SQ1: *What is the current flow of materials and information and who are the stakeholders in the supply chain of industrial housing construction?*

During the current situation analysis of chapter 6 various techniques were used to extract the current flow of materials, information and the stakeholders involved. During the supply chain mapping (6.2) a basic supply chain model was made in order to determine the boundaries of the materials and information flows and the basic stakeholders. Resulting in five levels of stakeholders; suppliers, CascoTotaal, contractors, consumers and customers. The basic supply chain mapping was also the input for the business scope diagram where the stakeholders for the process of CascoTotaal were determined. The most influential stakeholders are the materials suppliers of the different modules on the supply side of the process. For the internal process of CascoTotaal the: Office, Structural works factory and Finishing factory are the stakeholders and the main- and sub-contractors, customers and consumers are the stakeholders on the demand side of the process.
In order to find the physical flow of materials between the different stakeholders the SCOR model was used to map the materials flow. The results can be found in section 6.2.3 with the accompanying mappings in Appendix II and Appendix III. It was concluded during the SCOR model that all physical material flows converge at the finishing factory of CascoTotaal, but that the responsible party of these flows at that point in the model was the main-contractor. While the finishing factory just acts as a facilitator and intermediate storage of materials. For the mapping of the information flows the BPMN process mapping technique was used, the results are presented in section 6.3 and the information flow mapping can be found in Appendix IV. The main conclusion of the BPMN model is that during the information transfer from consumer to the CODP, the information is transferred between all intervening stakeholders even if these stakeholders do not add value to the information transfer. It was also seen that in order to start the process, two separate initiation points at the consumer and customer have to be initialised. Based on the combining of the BPMN and SCOR model it was seen that the point of specific consumer information required in the process shifts forward with every step further towards the actual construction of the house.

SQ2: *What are the positions of the customer order decoupling points in the current supply chain of industrialised housing construction?*

In order to determine the current positioning of the CODPs the results of the SCOR model supply chain mapping was combined with the BPMN process mapping in order to find the influence of the customer on the final product and where the physical material flow meets information flow (section 6.4). The results were translated to customisation levels using a combined model of (Barlow et al., 2003) and (Hoekstra & Romme, 1992) as described in section 4.2.1.d of the case study design. In order to gain a detailed overview of the current CODPs positioning, the mapping of the CODPs was performed on three different levels. The Product level, representing the final product or the house. The second level was the Product module as described in the product modularisation in section 6.1 and finally on the level of the Components that are used in the product modules. From this first analysis, it was concluded that depending on the level, the positioning of the CODP can vary significantly based on the point where the information is linked to the specific customer or consumer and the level of possible customisation per product module. However, during the current situation analysis the CODPs were only mapped from the customer perspective since in the current process, most of the decisions made during the process are made by the customer. Therefore, in order to fully answer the sub-question, a second CODP mapping was made from the perspective of the consumer (section 7.1). By combining both the customer and consumer perspective of the CODPs per product module, a comparison could be made using Figure 57.

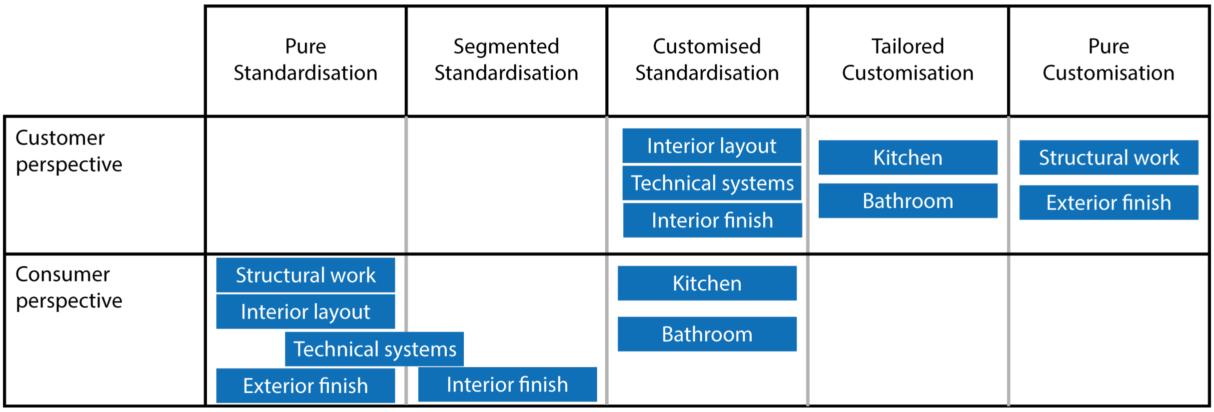

Figure 57: CODPs perspective comparison

By comparing both the positioning of the customer and the consumer, it can be seen that higher levels of customisation are possible in the current process as perceived by the consumer at the moment. The positioning of the CODPs with regards to customisability is now not only determined by the process itself, but also by the decision of the customer to transfer customisation features to the consumer or not. The decision-making process of the customer therefore needs to be incorporated in the creation of the most feasible positioning of the CODPs since it has a significant influence on the perceived level of customisability of the consumer.

Besides the CODPs positions on the product module level, it can be concluded that on the lower component level, most components used in the current product modules are Pure- or Segmented standardisation components. Product modules where components are mostly standardised can increase the level of customisation by increasing the ability to choose from more standardised components. This can be used to create a most feasible situation later.

SQ3: *What are the most influential performance indicators of the industrialised housing construction supply chain?*

During the current situation analysis (section 6.2.3.a), the performance attributes for CascoTotaal were extracted as part of the SCOR method based on personal observations and interviews conducted as seen in Appendix I and categorised according to the SCOR model performance attributes: Reliability, responsiveness, Agility, Costs and Assets (Supply Chain Counsil, 2015). As a result of the performance attributes analysis for CascoTotaal it was concluded that the two factors: Reliability and Responsiveness where the most important performance attributes of the current process. Where reliability dictates the ability of the process to perform a certain task as expected. For CascoTotaal, this is very important since in the finishing factory, a unit cannot move to the next task and station unless, the previous task has been completed fully and according to the required standard. Therefore, Reliability is very important for the smooth running of the entire process. Responsiveness is closely related to that since it dictates the speed at which a certain task is performed. In the finishing factory, there is a fixed takt time of one day per station, and all the tasks that have to be performed on that station need to be finished within the takt time. Therefore, responsiveness is also determining the smooth running of the process because when a task falls behind schedule, the entire process will be disrupted.
The most ability for improvement was found to be in the attributes of costs and assets. With regards to costs, the entire construction industry is costs driven and since CascoTotaal choose to construct their houses from concrete to prolong the lifetime of the product, the initial costs of production are higher compared to competitors. Also, the concept of not employing the workers in the finishing factory themselves will increase the final costs of the process. Therefore, much gains can be achieved for the costs attribute. With regards to assets, the efficiency of asset management is examined. In the current process, because the whole factory is climate controlled, the efficiency of the process is much higher when compared to traditional housing construction. However, CascoTotaal is currently not responsible for the workforce efficiency during the process. This is a large weak point of the entire asset attribute and can be improved in the future. In the current process, the agility attribute is the largest weak point of the entire current process. Since the process depends on main- and subcontractors to run the process, this causes the process to be very inflexible to changing circumstances or external influences. In order to excel the process to a higher level, agility should become a priority to improve in the near future.

SQ4: *What are the most influential external effects of industrialised housing construction?*

During the literature review on industrialised housing construction (section 3.5) multiple studies (Gann, 1996; Hsieh, 1997; Lu, 2007; Pan et al., 2008) on the external effects of industrialised housing construction were compared. It was found that the described external effects in these studies where all categorised into five effect categories: Construction time, Construction costs, Quality, Safety and Environment. Therefore, the current situation external effects mapping performed in section 6.5 compared the current process of CascoTotaal to the traditional housing construction method based on these five categories as described in the case study design in section 4.2.1.e. However, the determination of the exact external effects for the process of CascoTotaal was impossible since the required data on the process inputs and outcomes was not present at the time. In the current process, there were no performance

attributes that where actively measured. Therefore, a preliminary descriptive external effects analysis was made comparing the process of CascoTotaal to the traditional way of housing construction since the measuring of process data was out of the scope of this research.
The results of the preliminary external effects mapping show that there are negative and positive effects for all the five categories but that overall and except for the construction costs, the positive external effects outweigh the negative. This preliminary external effect comparison between the traditional housing construction method and the current process of CascoTotaal was later used in the external effects determination of section 8.3. where the preliminary results were used in order to further specify the external effects categories and the effects of repositioning the CODPs where extracted based on the expanded categories.

SQ5: *What are the most feasible Customer Order Decoupling Points in the supply chain model based on consumer preferences in The Netherlands?*

In chapter 7 of this report, a future scenario was created for the process of CascoTotaal. In this future scenario, the consumer preferences were transformed into most feasible CODPs on the product module level. By comparing the perspectives of the customer and consumer is was clearly seen that the positioning of the CODPs and the ability to customise the final product were not the same for customer and consumer. In order to explain this difference in perspective between the customer and the consumer a limitations analysis has been performed where the technical and logistical limitations of every product module were examined in order to see if for the customer or consumer would be limited by technical or logistical factors. From the limitations analysis, it can be concluded that the most influential limitations are present in the logistical factor of the structural work module. Since all other modules are added to the structural module, the logistical limitations for the structural work module are leading. The most influential limitations are: the total weight of the module that cannot be above 30T and the maximum dimensions which are; 5m wide, 10m long and 3,6m high in order to still be able to transport the final module by public roads. For the technical limitations, small limitations are found in various modules, But these module specific limitations are not limiting for the entire process and only impacted the specific module.
The next step to answer the sub-question is to find the preferences of consumers with regards to customisation in housing by using a previous study on housing preferences in The Netherlands (section 7.3) (Hofman et al., 2006). In order to translate the measured housing components into the defined product modules, a modularisation for the process of CascoTotaal was performed using a housing preference relation matrix. By adding all the expressed absolute importance amounts together, the Generational Variety Index (GVI) (Veenstra et al., 2006) was calculated per product module. However, in order to better be able to compare the modules to each other, the relative GVI was calculated for all product modules using the following equation:

$$GVI_{relative} = \frac{GVI_{module}}{\sum GVI_{module}} \times 100$$

The results of the GVI and relative GVI calculations show the relative influence of the consumer preferences on the process of the different product modules. The higher the relative GVI, the more preference is expressed by the consumer to influence the process for that module relative to the other product modules.

However, the GVI calculations are not suitable to draw conclusion on the relative importance of the consumer. The GVI only tells something about the impact on the process that the consumer preferences have relative to the other modules. In order to get a better view on the preferences for customisation the consumer expresses per product module, the average importance was calculated per product module. The average importance was calculated for every module individually and the relative average importance was calculated from this in order to be able to compare the modules with each other. Both the relative GVI and relative importance can now be compared for the process of CascoTotaal as presented in Figure 58.

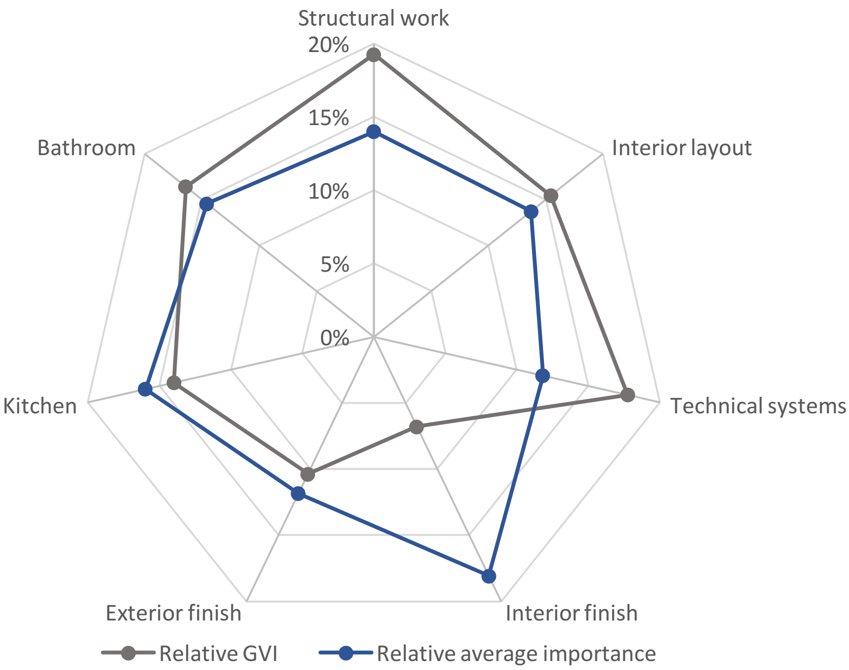

Figure 58: Relative GVI vs Relative average importance

By comparing the relative GVI (Grey line) and relative average importance (blue line) the difference between process impact and consumer preference can be determined. For example, for the Interior finish module, the consumer expresses a relatively high preference for customisation while the relative impact on the process is low. The opposite is true for the Structural work unit where the relative preference for customisation is low while the relative impact on the process is high. Together with the limitations analysis, the gap between the process impact determined by the GVI and the preferences for customisation expressed by the consumer, the most feasible positioning of the CODPs can be determined.
Starting with the preferences of the consumer, the most preferred positioning of the CODPs from the consume perspective were identified in section 7.5. This was done by creating a preferred CODP matrix adapted from (Schoenwitz et al., 2017) where the expressed average preference was plotted on one axis while the positioning of the CODPs and accompanying level of customisation were plotted on the other axis. The resulting positioning preferred by the consumer were extracted from this and added to the comparison in CODP positioning per product module (Figure 59).

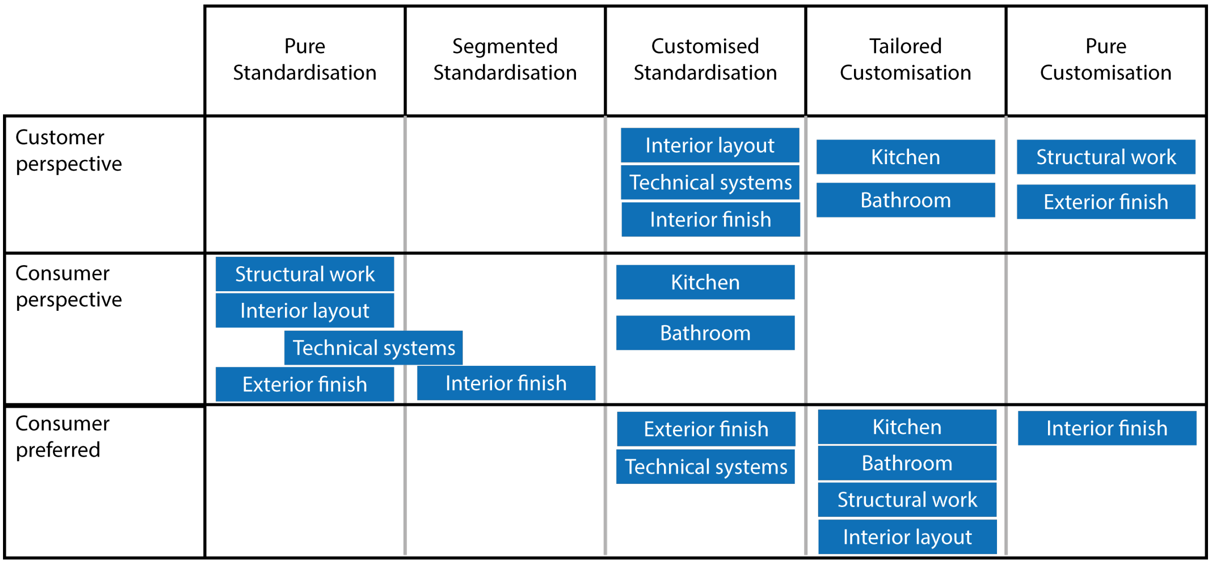

Figure 59: Preferred CODPs compared to current situation

With this exact positioning of the CODPs according to the preferences of consumers in The Netherlands, the most feasible positioning of the CODPs for the process of CascoTotaal can be determined. However, in order to do this a spread needed to be defined for the CODPs to be shifted up or down by introducing the module specific limitations and consumer preference. This spread was determined based on the CODP matrix adopted from (Schoenwitz et al., 2017). The spread for the CODPs to be placed in for CascoTotaal was determined in section 7.6.1 for every product module individually. By combining all the previous results, finally the positioning of the most feasible CODPs for CascoTotaal could be determined. This was done in section 7.6.2 where the trade-off for CascoTotaal was made between standardisation and customisation for every product module based on the determined spread possible and then adjusting the preferred positioning of the CODP per product module according to the found technical limitations resulting in the following positioning represented in Figure 60. In Figure 60 the light blue shaded areas represent the possible spread of the CODPs to be positioned in per product module, the dark blue areas represent the actual determined most feasible positioning of the CODP per product module.

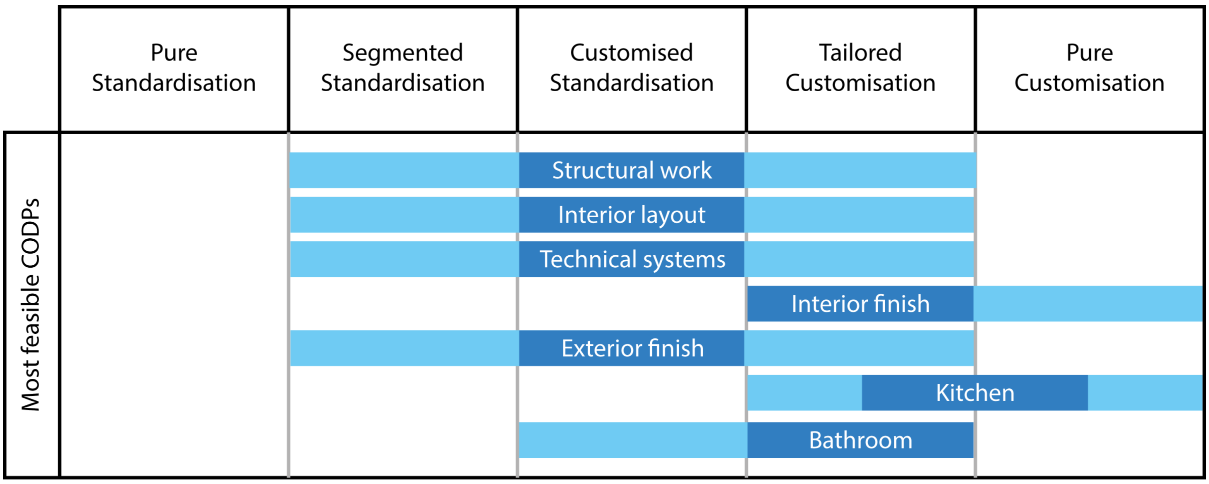

Figure 60: Most feasible consumer CODPs mapping for CascoTotaal

SQ6: *What is the influence of the most feasible CODPs on the performance indicators?*

The influence of the new most feasible positioning on the performance indicators can best be seen in the supply chain effect described in section 8.2 of this report. But, in order to compare the current positioning of the CODPs with the new most feasible positioning of the CODPs the two situations first needed to be compared. This was done during the gap analysis of section 8.1 where the difference between the current perspective of the consumer, customer and new most feasible positioning of the CODPs were compared for every product module following the model described in Figure 61.

The model describes that by combining the current positioning to the most feasible positioning, a test for alignment is made and when misalignment is found, a gap analysis should be performed on the misalignment. Then two effects can be found when closing the gap. The first is a market repositioning effect and the second is a process reconfiguration. For this research, the market repositioning will be examined later during the external effects analysis. In order to answer this sub-question, the process reconfiguration is further analysed by examining two supply chian effects: process effects for the internal reconfiguration and logistical effects for the external reconfiguration.

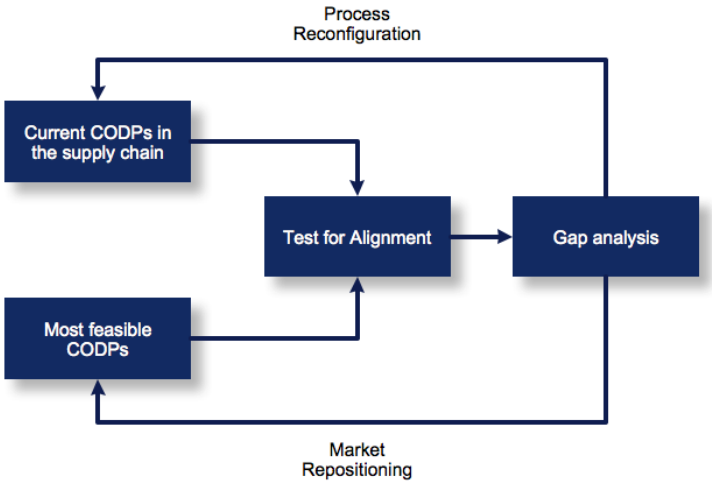

Figure 61: CODP alignment test (adjusted from (Schoenwitz et al., 2016))

The process effects of CascoTotaal are examined in section 8.2.1. where is can be concluded that, the main effects on the process of CascoTotaal are minimal as the limitations analysis already provided the information that there are very little limitations to incorporating consumer preference in the product. Nevertheless, it has been seen in the gap analysis that all modules need to increase their level of customisability for the consumer and this means the CODPs need to be repositioned. For most modules, except the kitchen and bathroom, this means that the point where the information stream meets the physical materials stream is moved further inside the process. The result is that more information is needed from the consumer before the process can start. When the information flow is further analysed using the BPMN information flow model (Appendix IV), it is seen that there are multiple stakeholders with non-value adding steps in between the consumer and the point where the information in needed during the production. Information streamlining can therefore increase the efficiency of the information flow and increase the performance attribute of reliability and responsiveness by decreasing information distortion and the amount of time the information needs to travel to the final position in the BPMN model where it is required by the process.

In section 8.2.3 the logistical effects are examined. It was concluded that in the current process, a mix of the anticipatory and reactive logistical models are used based on the ability to forecast the (sub-)components demand per product module. However, in the new CODPs positioning it is seen that all product modules require more customisation features to be added and that the position in the process where these features are chosen is shifted more

towards the consumer resulting in more fluctuations in demand created throughout the entire logistical process. This means that in most product modules a shift from the anticipatory model is made to the reactive model. But, changing to the reactive model means that the needed components and sub-components are only order once the consumer has made the decision, meaning that the logistical process has become more critical while the performance attribute of Agility will increase. To gain a better understanding of the logistical effects a more detailed analysis is made for every product module based on the logistical components of: Location, Inventory and Transportation.
From these three analysis, it is concluded that a strong long-term relationship should be used between the first-tier supplier and the finishing factory of CascoTotaal in order to optimise the logistical process. In the current process this partner is Bouwcenter Logus De Hoop, located very close to the finishing factory and the preferred supplier of CascoTotaal, while they are part of the same parent company. The relationship with Bouwcenter Logus De Hoop can be extended and needs to be extended in order to optimise the logistical process and minimise the negative effects on the Costs attribute and increase the Asset efficiency for transportation. Also, the Agility can be improved when Bouwcenter Logus De Hoop is willing to expand their assortment to suit the new positioning of the CODPs and the needed increase in customisability and accompanying customisation features per product module.

SQ7: *What is the influence of the most feasible CODPs on the external effects?*

In section 8.3 of this report the external effects are discussed using an expanded version of the external effects matrix and a first iteration of the market repositioning. The external effects matrix is expanded using the categories found in the literature review and combining these with the findings of the preliminary external effects analysis made during the current situation analysis. From the expanded external effects matrix it can be concluded that, the most influenced external effects are the off-site construction time at the finishing factory of CascoTotaal explained by the extra customisation features installed at the factory which decrease repetition and therefore, the amount of time per component to be installed will increase. The same lack in repetition and the amount of possible combinations of components increasing also influences the internal quality of the final product. Lastly the total construction costs are one of the largest factors in the external effects to be influenced by the introduction of consumer based customisation.
For the market repositioning of the house, the Spero 1 single family house is configured in multiple ways. In order to find the optimal housing market for it to be positioned in with the proposed customisation features. In order to calculate the market positioning, the housing valuation system as used by the Dutch government is used to determine the maximum allowable rent price the customer can ask from the consumer in both the social- and private rent housing market (Appendix VI). For the social rent housing market is concluded that in the current form, the Spero 1 with customisation features exceeds the maximum allowable number of points to be classified as social housing. In order to adapt the Spero 1 to fit within the category of social housing, customisation is no longer possible and therefore, the social housing market is an unfit market position for this research. For the private rent housing market, four configurations of the Spero 1 are constructed, a minimum luxury and a maximum luxury design are made within two categories, a non-energy neutral and an energy neutral version. When the results of these four configurations are summarised the following table is created:

	Non-energy neutral Minimum composition	**Non-energy neutral Maximum composition**	**Energy neutral Minimum composition**	**Energy neutral Maximum composition**
Awarded points	**186**	**211**	**174**	**199**
Maximum rent	€927,56	€1057,18	€865,31	€994,95
Energy compensation	-	-	€105	€105
Total monthly cost	**€927,56**	**€1057,18**	**€970,13**	**€1099,95**

By analysing the results of the four compositions, it is concluded that the positioning of the Spero 1 Single family house with the offered customisation features fits in the "mid-priced" private rent housing market currently stimulated by the Dutch government. These government stimulations are used to increase the number of households flowing from the social housing market to the private housing market and becoming independent of social housing programs. The new customisable Spero 1 single family houses fits perfectly into this "mid-priced" housing market with a rent price of 700 to 1000 euro per month excluding energy use or compensation. Even though the Spero 1 will be on the high side of this market, together with the advantages of the concept of CascoTotaal, the ability for the consumer to configure the houses to their preference should be an advantage for the customer since they can adjust their rent prices accordingly and be a stronger competitor.

9.2 Answering of the main research question

With the sub-questions answered, an answer to the main research question of this report can now be formulated:

Q1: What it the influence of consumer based customisation on the supply chain and external effects in industrialised prefabricated housing construction at CascoTotaal?

Based on this report it can be concluded that the method of prefabricated industrialised housing construction at CascoTotaal is very capable of offering competitive consumer oriented houses by introducing consumer based customisation. However, the influence of offering consumer choice on the process itself with regards to the supply chain and external effects is significant since the current process offers very little to no customisation possibilities for the consumer. This report therefore developed a future situation based on expressed consumer preferences in housing construction to introduce customisation at CascoTotaal. By comparing this future situation to the current, the influence on both the supply chain and external effects could be researched.
Besides the detailed effects discussed during the answering of the sub-questions, the most significant conclusion of this research is that even though the process itself is constructed as an industrial process, most of the underlying sub-processes and stakeholders involved still approach it as a traditional construction process. This can be seen in in the physical materials flow where mostly traditional housing construction materials are being used as well as in the information flows of the BPMN model consisting of traditional housing construction stakeholders and elaborate information transfers between.
Therefore, this research concludes that the introduction of mass customisation in the housing construction industry is not only influencing the supply chain and external effects, but also has a large influence on the entire housing construction way of thinking.

10 Recommendations

From the conclusions drawn in the previous chapter, various recommendations for both CascoTotaal and the academic society can be formulated.

10.1 Recommendations for CascoTotaal

In this section, recommendations are made for CascoTotaal in order to improve their current process and to implement the suggested customisation features. The advice is constructed based on the conclusions and findings discussed in this report together with the experience gained during the research and observations at CascoTotaal.

10.1.1 Performance measuring

During the research at CascoTotaal it was concluded that because the actual construction work in the finishing factory is performed by third party contractors, the process performance is hard to control by CascoTotaal. This is even more of a problem since there are no performance measurements taken for the current process. Therefore, in order to optimise the current and future process of CascoTotaal, it is strongly recommended that even though CascoTotaal is not responsible for the actual performance of the construction work, they do measure the finishing factory performance actively so that the impact of changes in the process can be calculated and the process can be steered on higher levels if needed.
When implementing a performance measurement system, it is recommended to CascoTotaal to follow a balanced approach following the performance attribute categories of the SCOR method in order to gain a complete overview of the entire performance spectrum: Reliability, Responsiveness, Agility, Costs and Assets.
The measurements of balanced Key Performance Indicators (KPI's) cannot only be used to steer the current process more effectively, but also to reconfiguration the current and future processes based on detailed process information in order to better be able to calculate and predict the reconfiguration outcomes.

10.1.2 Process reconfiguration

Closely linked to the collection of process data is the reconfiguration of the physical process. It was seen that with the introduction of customisation features, the configuration of the process steps inside the factory will become more critical as the interrelations between different product modules becomes more pronounced. An example of this can be seen in the interior finish, if for example tiling is applied, the whole process needs to be adjusted since two positions on the production line are needed (one for tiling and drying and one for grouting). This means that the entire process becomes more compact due to the limited amount of positions on the production.
In order to reconfigure the process to be able to incorporate customisation features as proposed in the most feasible CODPs positioning. Process information on the different sub-processes is needed to optimise these sub-processes. It is recommended to CascoTotaal to develop standardised sub-process blocks that can be rearranged on the production line based on the requested customisation features.
For this the sub-processes could be developed based on their cycle time. When now the exterior finish is developed, a brick slip finish will have three blocks (Insulation and window-/doorframes placement, Brick slip placement and Grouting). These three blocks all take up one day so three stations on the production line need to be reserved. However, all these

blocks happen on the exterior of the house, other blocks like the interior wall placement and technical systems can be simultaneously performed on the same stations and depending on their cycle time. When all the cycle times of the separate blocks and their interdependencies are known, the total process cycle time can be optimised. However, for these blocks to be developed, detailed process information is needed and needs to be measured.
The development of these process blocks can also help CascoTotaal every time a new project is started since at the moment all process positions are redeveloped for every project. By developing standardised blocks with customisation variation known, the process can simply be adjusted per project during the starting phase of the project. A second benefit of the standardisation of process steps will be that this can help with the planning of customisation features when different customisation features are introduced as proposed in this report.

10.1.3 Information optimisation

Besides the physical process steps performed at the factory it is recommended for CascoTotaal to optimise their information flow. As seen during the process mapping and the resulting BPMN model, the information flow throughout the process of CascoTotaal is not optimal and numerous non-value adding information transfers are present in the process. This is mostly visible in the information flow with regards to the preferences expressed by the consumer towards the contractor who has to apply these to the final product. The information is transferred though every stakeholder in between adding more possibilities for information distortion or delay. Besides this, there is no standardised way of transferring information which can lead to information mismatch of loss. Therefore, it is recommended that CascoTotaal together with their partners or main stakeholders invest in the optimisation of the information process, standardising the information transfer method and optimising the flow of information through the process by minimising the number of information transfers and removing the non-value added stakeholders from the main information flow.

10.1.4 Implementation roadmap

Since the recommendations to CascoTotaal are very diverse, this implementation plan is constructed (Figure 62) in order to differentiate between direct gains from implementations and long-term gains that require more time or are more difficult to implement.

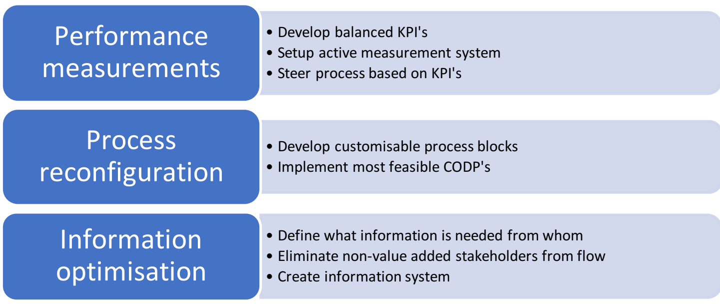

Figure 62: Implementation roadmap

For CascoTotaal in order to implement the suggested changes with regards to process reconfiguration and information optimization it is very important to get a more detailed view of the process performance. It is therefore advised to start the implementation with the development of balanced KPI's based on the SCOR performance attributes. In the short term, these KPI's allow CascoTotaal to actively steer the process based on data and get a better view of the performance. However, in order to succeed in this, a structural measurement system should be incorporated in order to extract the required information form the process. Over time, these measured KPI's will then become more valuable as more data is gathered about the process and long-term recommendations can be implemented with higher accuracy since the measurements over time are needed to incorporate the proposed process

Blocks into the finishing factory based on for example sub-process cycle time. But for these blocks to be incorporated they have to be pre-engineered. It is advised to start with the development of the process blocks with the highest potential for consumer satisfaction gain and lowest process impact as seen in the Relative GVI vs Relative average importance calculations in order to see quick results once implemented. Examples of these high gain modules are the Interior finish and Kitchen. For the Interior finish module, the different exterior finishes CascoTotaal wants to offer to the consumer need to be defined and the application time for these finishes needs to be defined in process blocks. For the Kitchen module, most of the construction work happens at the kitchen manufacturer. This enables CascoTotaal to incorporate a high level of customisation without significant process influences. The only process blocks CascoTotaal needs to develop are the "kitchen layout" (to standardise the technical systems connections and interior wall placements) and the "kitchen placement" process blocks.

However, it is seen that in order to develop detailed process blocks, information like installation time of the kitchen or the exact interior finish choices of the consumer are needed from different stakeholders. It is therefore advised that after the development of the process blocks, the required information and stakeholders needed per process block are defined. It is advised to define these after the development of the process blocks since the detailed requirements of these blocks is needed as an input for the information optimisation.

Based on the developed process blocks, it is advised to first define what information is required and from whom this information is required before the total information flow is transformed. The most feasible positioning of the CODPs should give a good overview of the required stakeholders and where the information is required in the process. However, based on the detailed process blocks constructed based on the most feasible CODPs it should be possible to eliminate non-value added information stakeholders.

As a last step in the implementation roadmap, it is advised to optimise the information transfer system so that the critical information reaches the critical stakeholders without intervening steps. The information system generation is the last step in process optimisation iteration since it is dependent on all previous steps in the roadmap to be performed in order to optimise the amount of information to be transferred and the minimal number of intervening stakeholders to be present in the information flow.

10.2 Recommendations for further research

The main goal of this research was to explore the trade-off between standardisation and customisation possible for industrialised housing construction in The Netherlands. This was achieved by developing a literature based case study and researching the outcome of this case study at CascoTotaal, the initiator of this research. During the case study design construction and research at CascoTotaal, simplifications were made based on the available literature at the time and case specific assumptions needed to be made. Nevertheless, several possibilities for further research have been identified to expand the academic knowledge on the topic of industrialised housing construction and to proceed on this research.

10.2.1 Case study expansion

The research described in this thesis has been performed based on a single case study at a Dutch industrialised housing construction company due to the limited time available. As discussed earlier during the construction of the case study in chapter 4 of this report. In order to increase the generalisability of the case study, the single-case holistic approach used in this research can be expanded to a multiple-case holistic case study by using the same case study design and protocol at other industrialised housing construction companies in The Netherlands and comparing the outcomes. This will increase the generalisability by using multiple single cases with slightly different approaches to industrialised housing construction.

10.2.2 Comparison with other countries

This research is only focussed on the industrialised housing sector in the Netherlands by comparing a possible future situation and current situation within a single company. As discussed in the literature review, in other countries such as Germany, comparable studies have been performed. However, the consumer preferences in other countries have found to be different. A possibility for future research would therefore be to compare the results found in The Netherlands with comparable researches from other countries. This would increase the academic knowledge with regards consumer preferences differences and the impact on housing construction.

10.2.3 Consumer preference research in The Netherlands

During the literature study, it has been found that very little detailed knowledge exists regarding the preferences of (future) house owners in The Netherlands. From interviews with housing associations it was concluded that detailed information about consumer preferences does exist, but this is considered as internal company knowledge. Due to the limited time available for this research, the most detailed information available has been used, but a recommendation for future research and to improve the implementation of this research would be to expand the academic knowledge on more detailed consumer preferences with regards to housing design in The Netherlands.

10.3 Generalisation of the results to other industries

Besides the housing construction industry, other industries are also confronted with a comparable trade-off between standardisation and customisation. In the recent decade, mass customisation has been researched heavily as a strategy in order to respond to the increasing demand of consumers for affordable customisation (Da Silveira, Borenstein, & Fogliatto, 2001; Fogliatto, da Silveira, & Borenstein, 2012). The general notion of the findings in this report discuss the introduction of a modular product and process in order to solve the trade-off problem in an industry primarily oriented towards pure standardisation or customisation. From the strategy of mass customisation, two generalisations can be made from the results in this report. The first is categorised as bottom-up mass customisation where customisation is consumer driven and preferences are translated into a modular design. A good example is the development of ERP systems in the ICT sector where the standard system is fully customised to the consumer preferences. The second category is top-down mass customisation where the product or process is developed as modular and then forced on to the consumer. This is the most common type and seen in for example the automotive industry where choices are often forced on to the consumer from a standardised design with limited pre-engineered choices based on the most efficient process or product configuration. This research has proven that the disadvantages of both approaches can be solved by the bidirectional approach. To work from both sides, simultaneously, towards the most feasible situation. Starting from the customer preferences and adjusting the process and product. All within a spread of acceptable customisation levels from the consumer perspective and adjusting the CODP to the limitations of the product and process.

11 Reflections

As the closing chapter to this report, a reflection on the research performed and my personal challenges during the research is given. The reflection discusses the challenges encountered during the research and how these challenges have been solved in order to come to the results described in this thesis.

During the construction of the research, it was chosen that it would be performed as a case study. However, in the academic world, case studies are often criticised to be weak since the issues that are researched are mostly not found randomly, or only to be specific to the single case in the case study and not generalizable. For this research, a case study was specifically chosen for the possibility to expand the research in other industrialised housing construction companies by using the same basic design as described in the case study protocol. However, since the analysis of the supply chain and information process are case specific, the results are harder to generalise to the industry as a whole. But, as discussed in the previous section, the results of on customisation possibilities in industrialised housing construction based on consumer preferences can be generalised to the entire industry. Also, the research itself provided insight for other industries on how to incorporate mass customisation by using a bidirectional approach.

During the literature review it was discovered that in the housing construction industry there is a lack of detailed publicly available information on consumer preferences. For this research, the level of detail in the consumer preference measurements dictates the precession of the CODPs repositioning. In order to solve this problem, the information available from the research performed by (Hofman et al., 2006) was first transformed to fit the process modularisation of CascoTotaal, thereafter a spread in the positioning of CODPs was introduced to cope with the possibilities of changes in consumer preferences. By introducing a spread in the possible CODPs, the results are adjusted for the possibility of changing consumer demands and preferences. By comparing the results with the positioning of the CODPs found by (Schoenwitz et al., 2017) it could be concluded that the positioning of the CODPs was comparable between the two researches. Therefore, it can be concluded that the introduction of the spread in possible CODPs positioning could be made without significantly decreasing the reliability.

During the research at CascoTotaal, it became clear that there was a lack of existing process performance data. This prevented to supply chain and process mapping to be performed to the level of detail as was preferred at the start of this research. By using the scheduled interviews with different stakeholders throughout the supply chain and using these interviews to get a more detailed overview of the information and material flows the lack of performance data was reduced. By using these flows the CODPs could be mapped without detailed process performance information. During the later stages of the research, the information available from interviews for the process and the supply chain proved to be sufficient for the analysis on the CODPs repositioning. The lack of process data did prevent a more detailed analysis of the external effects, however, for this report, the change in effects could be analysed, but the magnitude of the change could not be determined. Therefore, the recommendation to CascoTotaal was given to measure more process data in order to better control the process and be able to determine the external effects of changes in the process or product.

Glossary

Component or Product component **–** Sub-sections (parts or assemblies) that together with other components form a (product) module (Figure 63).

Consumer **–** A person who uses a product but was not the one who was involved in the direct purchase or exchange transaction of that product

Customer **–** A person or company who is engaged in a purchase or exchange transaction.

Customer Order Decoupling Point (CODP) **–** The point in a supply chain where the product is linked to the order and/or preferences of the customer.

Module or Product Module **–** A modularised part of the final product (Figure 63).

Modularization **–** The categorization of a product based on a set of predefined features.

Prefabricated (Prefab) **–** The fabrication of a product or (large) sections of the product under controlled conditions in a manufacturing site and transporting these to the final construction site when needed.

Product **–** The final end product as produced by the company the product of CascoTotaal for example is a house (Figure 63).

Takt time **–** The maximum amount of time the product needs to be worked on in order to satisfy customer demand.

Unit or Product unit **–** One concrete structural module of CascoTotaal as to be finished in the finishing factory and transported to the final construction site. The Spero 1 single family home consists of two Units.

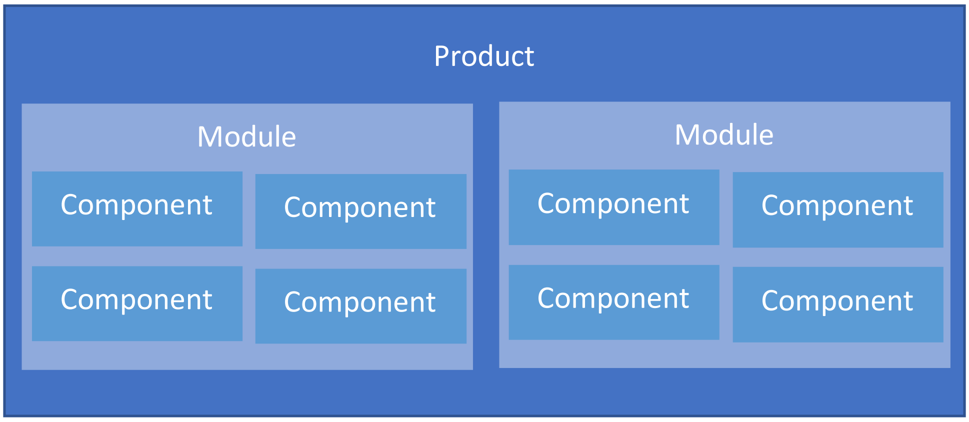

Figure 63: Product, Module and Component

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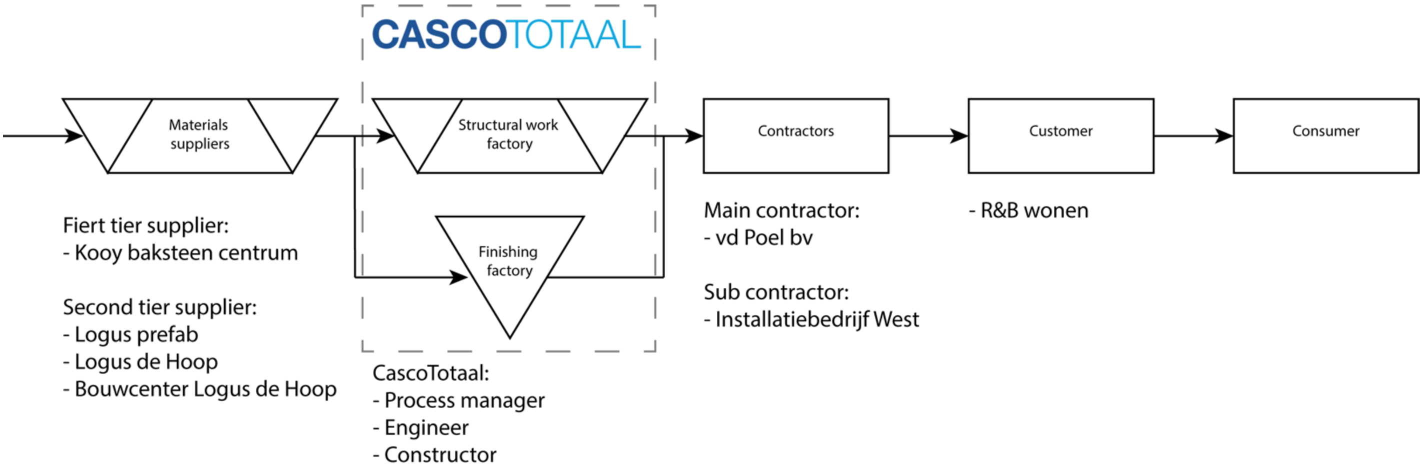
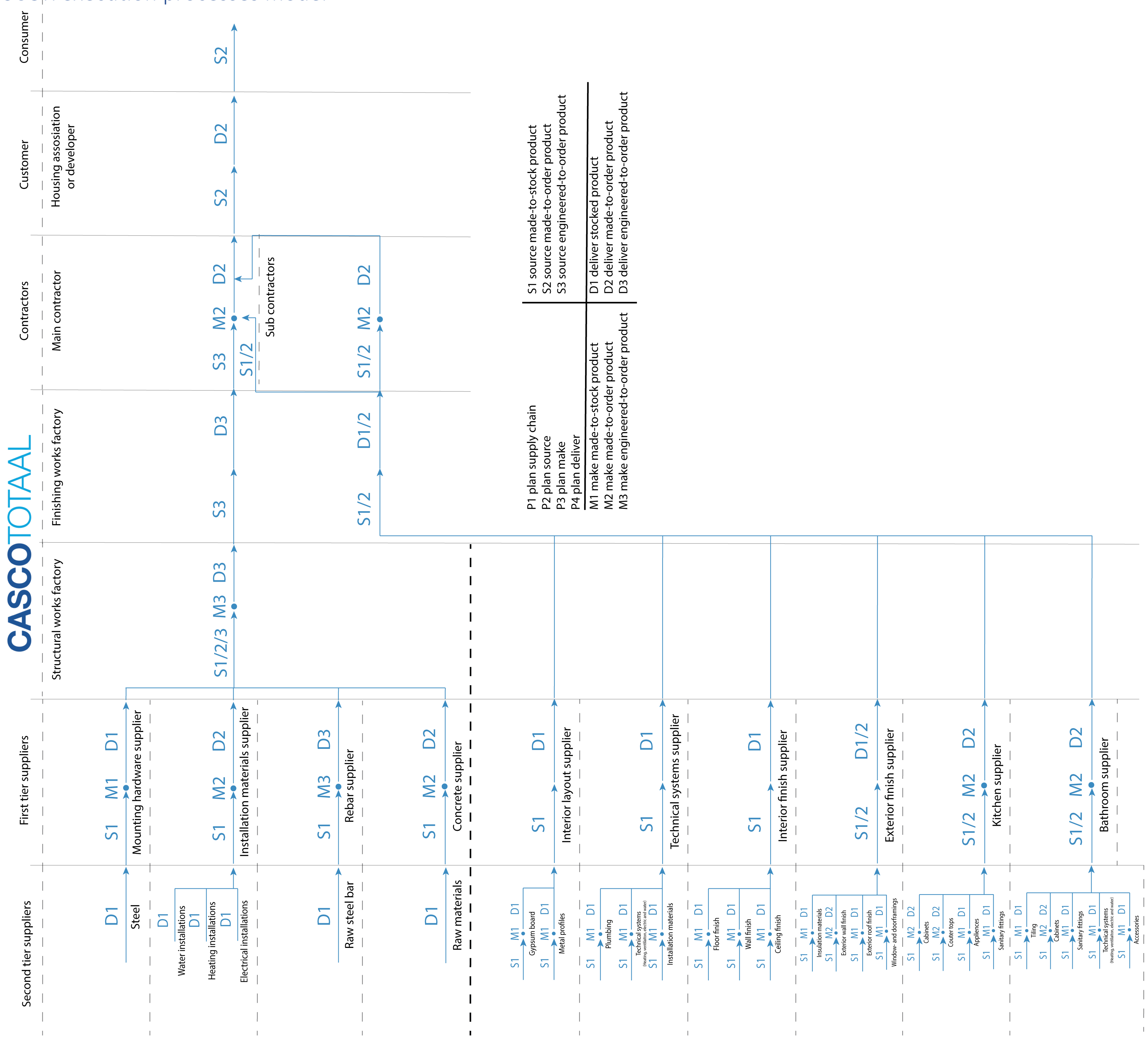
Appendix I Expert interviews



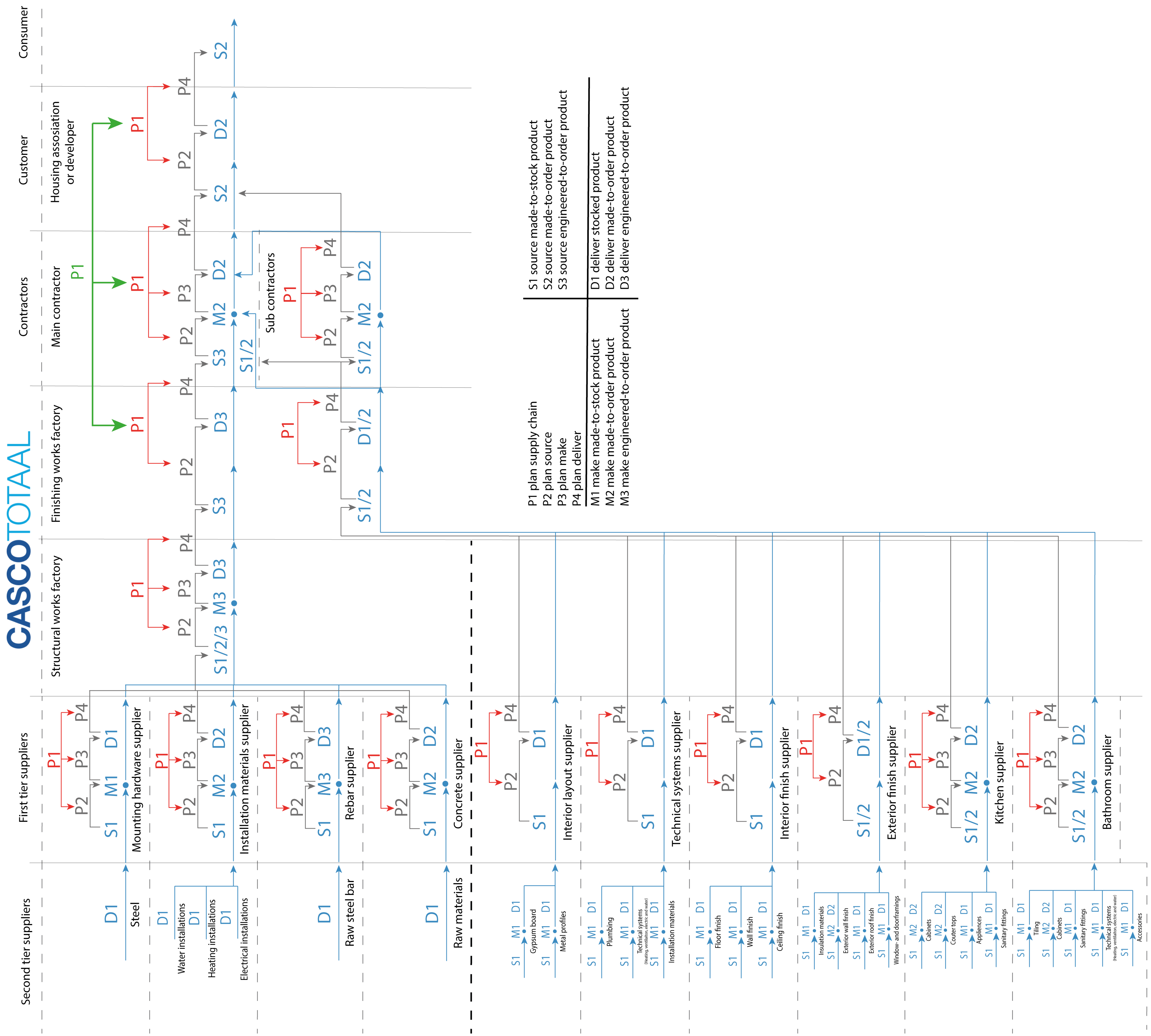
Interviewee		Purpose of the interview
Name: Company: Function: Date: Location:	Marco de Raad Vd Poel bv Projectleider March 6th 2017 Terneuzen	Vd Poel bv is the current main contractor working at CascoTotaal. Therefore, this interview was used to find the roll of the main contractor in the supply chain, the goods flow and information flow. Also, the impact of consumer choice was discussed
Name: Company: Function: Date: Location:	Marco Danen R&B wonen Projectleider March 14th 2017 Heinkenszand	The interview was conducted find the roll of the housing association in the supply chain. Besides this, the interview was also used to find external factors important for the consumer since the housing association has direct contact with the consumers.
Name: Company: Date: Location:	Pieter de Jong CascoTotaal March 20th 2017 Terneuzen	During the interviews within CascoTotaal the internal process was discussed and observed with Pieter de Jong. The steps necessary to complete the house were discussed throughout the process and the different uses of the separate subsections was discussed. Also, the modularization of industrialised housing construction at CascoTotaal was made clear during this interview.
Name: Company: Date: Location:	Roald van den Berghen CascoTotaal March 27th 2017 Terneuzen	For the construction of the structural section as produced by CascoTotaal Roald van den Breghen was interviews as to make clear what the subsections of the structural module are and how these are made up. The different stakeholders and dependencies involved in the constriction of the structural model were also discussed.
Name: Company: Function: Date: Location:	Michiel Selles Installatiebedrijf West Owner April 3rd 2017 Terneuzen	The main focus of this interview was to get the supply chain involvement of the subcontractor. Therefore, Installatiebedrijf West was chosen and the owner was interviewed about the role of the subcontractors in the supply chain of CascoTotaal and industrialised housing construction over all. Also, the performance indicators for the subcontractors were discussed and finally the effects of the industrialised housing construction on the subcontractors was clarified.

Name: Company: Function: Date: Location:	Robert Goris Kooy baksteencentrum Account manager April 5th 2017 Bilthoven	Kooy baksteencentrum was chosen to interview as a second-tier material supplier. Kooy baksteencentrum is the material supplier for brick slips at CascoTotaal. During the interview the process of second tier material suppliers was discussed and the involvement in the total supply chain was one of the talking points. Also, the effects of consumer choice in the supply chain from a second-tier material supplier was one of the points of the interview.
Name: Company: Function: Date: Location:	John Vette Logus Prefab Adjunct Directeur 6th April 2017 Hamond-Achel	From the first-tier supplier of the module bathroom, an interview at Logus prefab was organized. During the interview the assembly process of prefabricated bathrooms was discussed and the options of consumer choice in this process were analysed. Also, the impact on the external effects by prefabricating bathrooms was discussed during the interview. The main two goals of the interview were to find the impact on the traditional supply chain when bathrooms are prefabricated. And the external effects to the rest of the surroundings.
Name: Company: Function: Date: Location:	Irwin de Smet Logus de Hoop Head of showroom April 10th 2017 Terneuzen	Besides the module bathroom the module Kitchen also consists of large sub-assemblies being built in and external factory. Also, the module kitchen has a number of consumer choices that can be incorporated. Therefore, an interview was held at the kitchen supplier of CascoTotaal. The interview focused on the supply chain location of the kitchen in industrialised housing construction and the integration of consumer choice in the product. Also, the effects on the supply chain and external effects of adding or deleting choice options were discussed during the interview.
Name: Company: Function: Date: Location:	Evert Kuijk Bouwcenter Logus de Hoop Head construction materials May 1st 2017 Terneuzen	The purpose of this interview is to find the involvement of the first-tier raw building material supplier in the supply chain of CascoTotaal. Since Bouwcenter Logus de Hoop is the preferred supplier of CascoTotaal and facilitates in the material supply between the second-tier materials suppliers and the inventory of the finishing factory of CascoTotaal this interview was used. The primary purpose of the interview was to find the materials and information flow of the first-tier materials supplier in the supply chain. A secondary purpose that the interview was used for was the extraction of possibilities of consumer preference integration on a material level. During the interviews possibilities and limitations with regards to the impact of information and goods flows with the integration of consumer specific ordering were discussed for this secondary purpose.

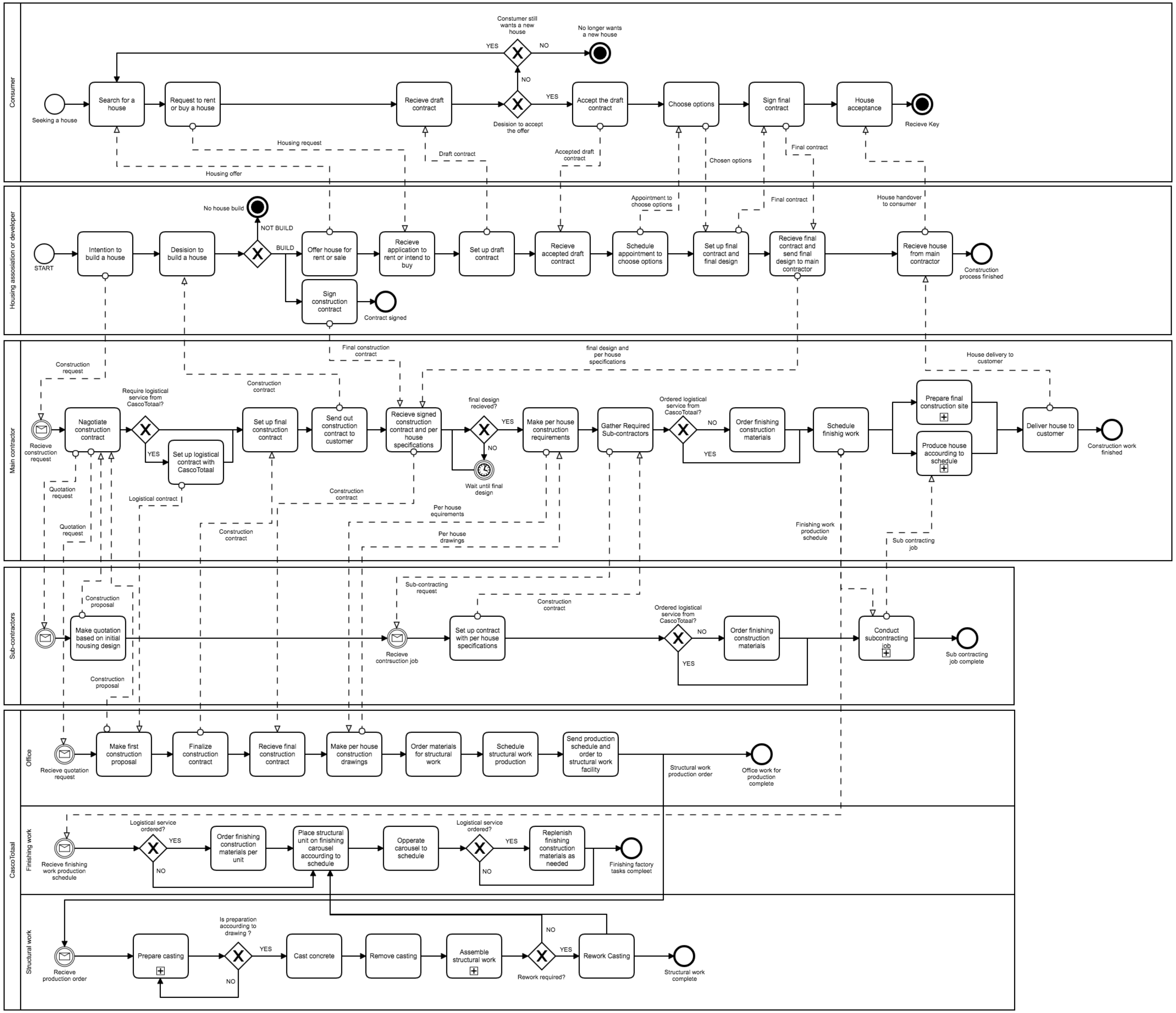
Appendix II SCOR execution processes model

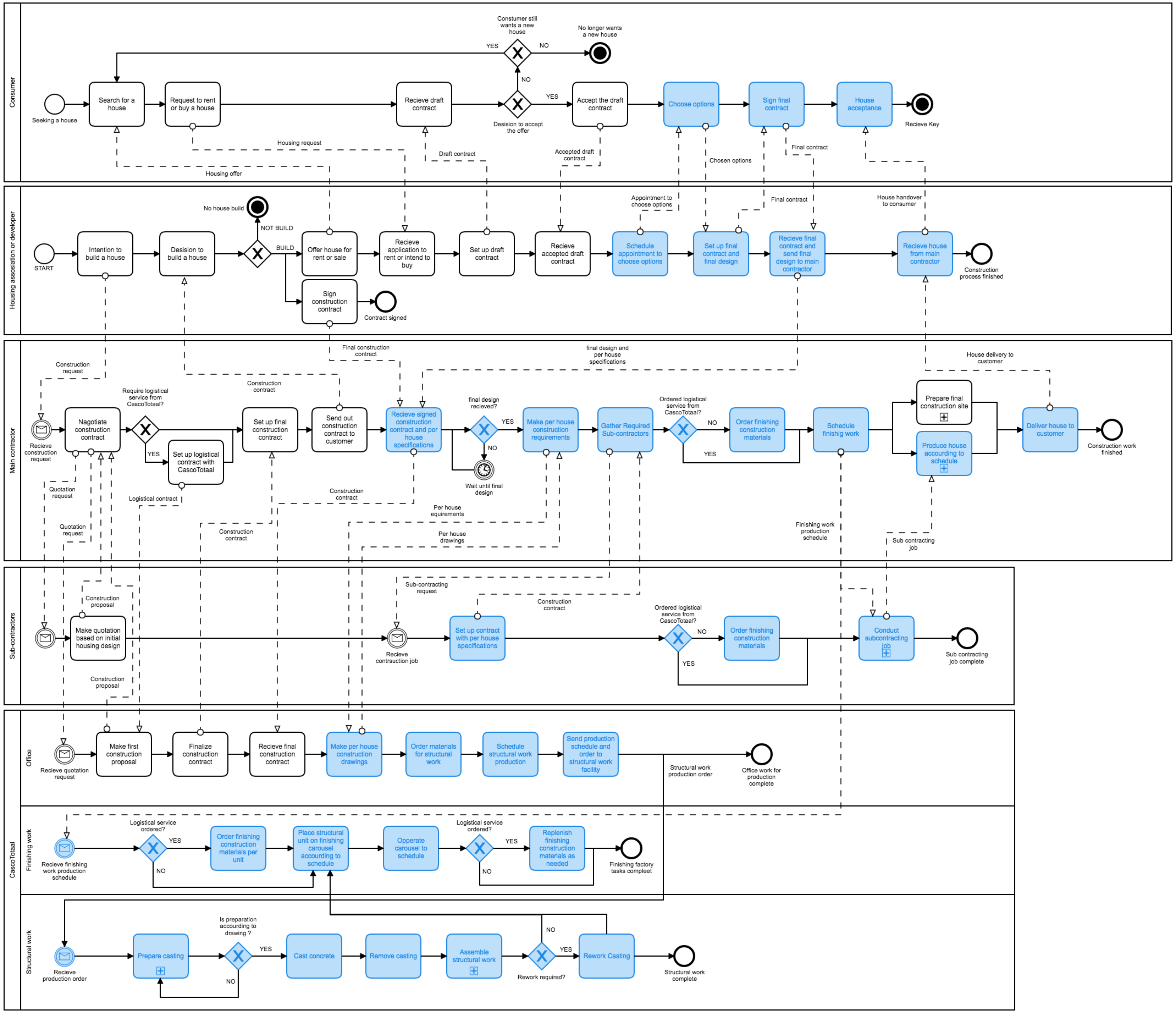


Appendix III SCOR Thread diagram of CascoTotaal



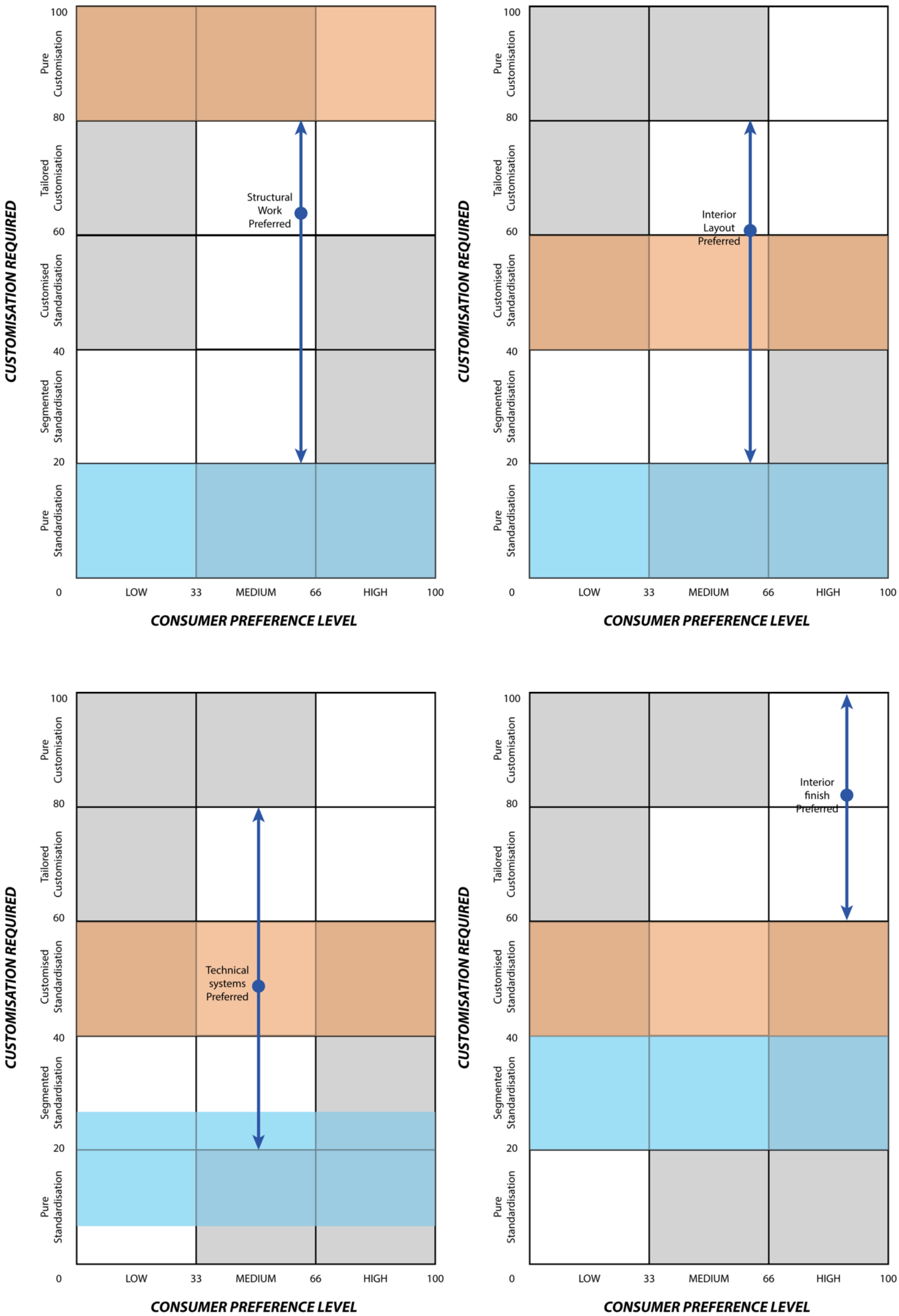
Appendix IV BPMN CascoTotaal

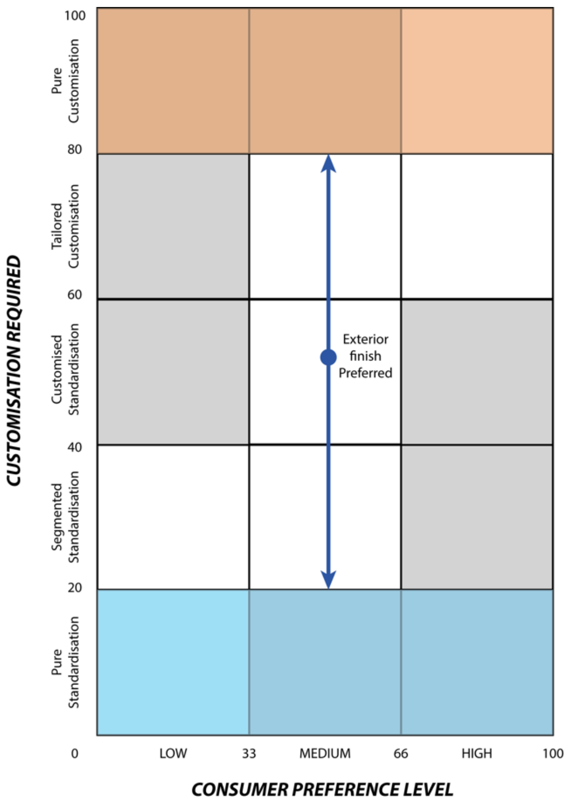


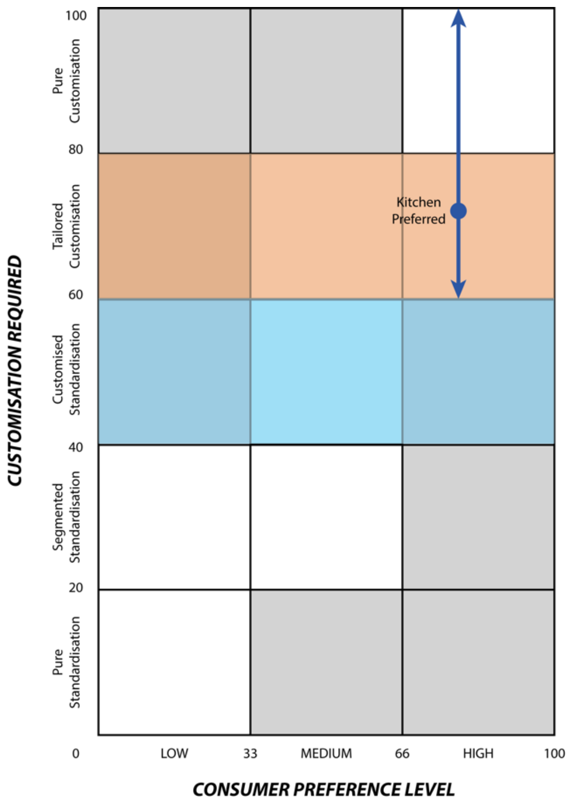


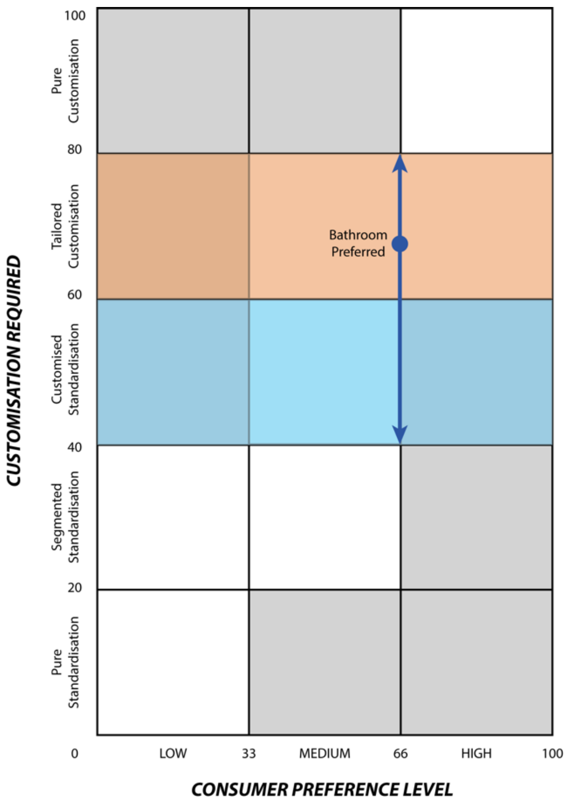
Consumer
Housing association or developer
Main contractor
Sub-contractors
CascoTotaal
Office
Finishing work
Structural work
Consumer still wants a new house
No longer wants a new house
YES
NO
Seeking a house
Search for a house
Request to rent or buy a house
Recieve draft contract
Desision to accept the offer
Accept the draft contract
Choose options
Sign final contract
House acceptance
Recieve Key
Housing request
Housing offer
Draft contract
Accepted draft contract
Chosen options
Final contract
Appointment to choose options
House handover to consumer
No house build
NOT BUILD
BUILD
START
Intention to build a house
Decision to build a house
Offer house for rent or sale
Recieve application to rent or intend to buy
Set up draft contract
Recieve accepted draft contract
Schedule appointment to choose options
Set up final contract and final design
Recieve final contract and send final design to main contractor
Recieve house from main contractor
Construction process finished
Sign construction contract
Contract signed
Construction request
Final construction contract
final design and per house specifications
House delivery to customer
Require logistical service from CascoTotaal?
Construction contract
Recieve construction request
Negotiate construction contract
Set up logistical contract with CascoTotaal
Set up final construction contract
Send out construction contract to customer
Recieve signed construction contract and per house specifications
final design recieved?
Wait until final design
Make per house construction requirements
Gather Required Sub-contractors
Ordered logistical service from CascoTotaal?
Order finishing construction materials
Schedule finishig work
Prepare final construction site
Produce house accourding to schedule
Deliver house to customer
Construction work finished
Quotation request
Logistical contract
Per house equirements
Per house drawings
Finishing work production schedule
Sub contracting job
Sub-contracting request
Construction proposal
Make quotation based on initial housing design
Recieve contruction job
Set up contract with per house specifications
Ordered logistical service from CascoTotaal?
Order finishing construction materials
Conduct subcontracting job
Sub contracting job complete
Recieve quotation request
Make first construction proposal
Finalize construction contract
Recieve final construction contract
Make per house construction drawings
Order materials for structural work
Schedule structural work production
Send production schedule and order to structural work facility
Structural work production order
Office work for production complete
Logistical service ordered?
Recieve finishing work production schedule
Order finishing construction materials per unit
Place structural unit on finishing carousel accourding to schedule
Opperate carousel to schedule
Replenish finishing construction materials as needed
Finishing factory tasks compleet
Is preparation accourding to drawing ?
Recieve production order
Prepare casting
Cast concrete
Remove casting
Assemble structural work
Rework required?
Rework Casting
Structural work complete

Appendix V CODPs spread for CascoTotaal per product module




CUSTOMISATION REQUIRED
100
Pure Customisation
80
Tailored Customisation
60
Customised Standardisation
40
Segmented Standardisation
20
Pure Standardisation
0
LOW
33
MEDIUM
66
HIGH
100
CONSUMER PREFERENCE LEVEL
Exterior finish Preferred


CUSTOMISATION REQUIRED
100
Pure Customisation
80
Tailored Customisation
60
Customised Standardisation
40
Segmented Standardisation
20
Pure Standardisation
0
LOW
33
MEDIUM
66
HIGH
100
CONSUMER PREFERENCE LEVEL
Kitchen Preferred


CUSTOMISATION REQUIRED
100
Pure Customisation
80
Tailored Customisation
60
Customised Standardisation
40
Segmented Standardisation
20
Pure Standardisation
0
LOW
33
MEDIUM
66
HIGH
100
CONSUMER PREFERENCE LEVEL
Bathroom Preferred

Appendix VI Logistical effects analysis per product module

Structural work

At the moment, the construction method of the structural work modules is sales driven. The modules are produced when the house is sold to the customer and manufactured to the consumer specifications. Therefore, the total structural work is a reactive logistical process. But, the separate components have different logistical processes. This can also be traced back in the current situation SCOR thread diagram (Appendix III). Here it can be seen that in the current process, the components concrete and rebar are produced once the house is sold and have reactive logistical processes. The mounting hardware is sourced from a local stock that is replenished based on the forecasted sales and are therefore anticipatory. The installation materials are also sourced from a local stock, but are installed to the customer specifications. Therefore, the installation materials are anticipatory since the materials are purchased based on forecasted demand and only the application of the materials is responsive. Therefore, in the current situation, the same logistical pitfalls exist as would be for anticipatory with regards to the installation materials.
If the CODP is shifted towards the most feasible level of customisation. It is seen that the module will still be manufactured once the house is sold, this means that the responsive logistical process will still be the most suited for the structural work module. The logistical processes of the components in the new situation will also not be impacted by the changing CODP. The concrete and rebar are still house specific and will use the responsive system since this is the most efficient system if the process is structured right. For the mounting hardware and installation materials it is not preferable to change the logistical system since the materials used are of low value. Also for the installation materials, the fluctuation in materials needed will be more fluctuating when the consumer is getting the choice to reposition the sockets and switches in the outer structural concrete walls.

Location

The manufacturing location of the structural work is located next to the finishing factory of CascoTotaal and will not move from one project to the other. However, the locations of the component suppliers are not all located in the same area as the manufacturing location. For the concrete used in the casting of the structural work, the concrete plant is located next to the structural work factory and is part of the same parent organisation as CascoTotaal. This ensures very rapid logistical changes or changes in demand can be absorbed. The component rebar is also produced by a sub-company of the same parent company as CascoTotaal, but it is not located closely. The rebar is produced at the De Hoop Pekso in Oosterhout, 130 kilometres away from CascoTotaal and transported in batches to the structural work factory according to the production planning made before every product. In the new position of the CODP, this will not change since the decisions of the structural work dimensioning, which are the most important factor for the rebar, are still with the customer. For the mounting hardware and installation materials, local suppliers are used since these materials are not supplier specific and can be ordered from multiple sources. However, in the new positioning of the CODP, the fluctuation in demand for especially the installation materials can increase, resulting in less reliable forecasts. Therefore, the relationship between the local suppliers and the finishing factory of CascoTotaal should increase to accommodate for a better information and ordering system in order to cope with the new fluctuating demand.

Inventory

Inventory only exists for the installation materials and mounting hardware in the current process. The rebar and concrete are made-to-order and are delivered just in time for the production of the structural work modules. In the new CODP positioning with an increase in possibilities for customisation for the technical systems, the fluctuation of demand installation materials will increase. Therefore, the inventory management of the installation materials will be more critical. However, the installation materials are low value products and adding extra inventory in order to cope with fluctuating demand will not have a significant increase in inventory value. Nevertheless, a good balance between inventory replenishment from local suppliers and local inventory should be found in the new situation.

Transportation

For the inbound transportation effects of the structural work, the new and current situation are very comparable since there are little changes in the materials needed and amount of materials that need to be transported to the structural work factory. The components with the most fluctuation (mounting hardware and installation materials) are all sourced locally and in larger quantities to replenish the local stock at the structural work factory based on forecasting. On the outbound side of the production, the structural work is the main module that all the other modules are installed on. The external transport from the finishing factory to the final construction site is also a large logistical factor in the process of CascoTotaal. At the moment, the costs required to transport the finished units to the final location are 1000 euros per unit for the first 150 kilometres and 100 euros for every 40 kilometres beyond that. When this is compared to the total logistical costs and the total construction costs of the final product this is not a deciding factor. Besides this, as discussed in the limitations analysis, the dimensions of the final product together with the maximum weight are limiting to the external transport of the final unit. These maximum values do not change when customisation is introduced, but the final weight of the unit can change with the introduction of customisation. As long as this does not go above the maximum, it is not a problem. Therefore, the final weight of every unit constructed has to be calculated before the construction starts in order to stay below the maximum transportable weight of 30T.

Interior layout

The interior layout module is driven by the design of the module and the amount of forecasted material and labour needed to install the module in the final unit. This is also seen in the SCOR thread diagram (Appendix III) where all the components of the interior layout module are sourced from local stock. The logistical process of the interior layout can therefore be categorised as anticipatory since the amount of material is forecasted and ordered in order to create a local inventory. However, in the new process where the interior layout is customisable by the consumer, the amount of materials needed in the final product can differ greatly based on the design the consumer choses. This means that forecasting will be less reliable. In the new process, the introduction of a responsive logistical system is preferable due to the high volume and low value of the products in the current inventory. Since the components of the interior layout are of low value and have a high volume, the restricted inventory possibilities of the finishing factory should be used optimally. This means that a minimum safety stock should be created in order to cope with fluctuating demand on the short term, but the labour and material purchasing should be adjusted to the actual demand once the design of the houses are in their final stage.

Location
During the current situation analysis, it was seen that the current first-tier component supplier of the interior layout (Bouwcenter Logus De Hoop) is also the first-tier component supplier of other modules. Boucenter Logus De Hoop is part of the same parent company as CascoTotaal, and therefore, the communication lines and relationship between the two can be optimised within the structure of the parent company. However, the components needed for the interior layout (gypsum board and metal profiles) are not dependent on the supplier and can be sourced from a variety of suppliers. For the new process configuration, it is preferable to commit to one supplier and setup a long-term relationship with a responsive logistical system. The location of Bouwcenter Logus De Hoop being so close to the finishing factory of CascoTotaal can help with this.

Inventory
In the current process, the inventory is mostly placed at the finishing factory of CacoTotaal. The local inventory at the finishing factory is replenished by Bouwcenter Logus De Hoop every 4 to 5 housed (8 to 10 modules) from their own local stock. This inventory components have a high volume and take up a lot of space on the limited factory floor. However, the value of the components is very low. Therefore, value-to-volume ratio does not justify the amount of inventory placed at the finishing factory in the current process where the amount of needed materials is very predictable and easy to forecast with known quantities of houses to build. In the new process where the layout will be customisable by the consumer, the predictability of materials needed in earlier stages of the process will be lower. In order to cope with the amount of fluctuation in demand, the inventory management of the components will become more critical. In order to cope with this, the inventory can be managed in two ways. The first way of inventory control is by determining a minimum safety stock needed for continuous production and ensuring this minimum is always present in the finishing factory. The second way of controlling the inventory is through rapid replenishment form local stock at Bouwcenter Logus De Hoop and just-in-time delivery to the finishing factory. This second way of controlling the process would be preferable but is more dependent on the information stream being strong. Since the first-tier component supplier is located so closely to the finishing factory, the rapid replenishment of materials in a just-in-time way would be possible if the amount of transportation needed can be justified.

Transportation
Currently, the products needed are all transported towards the component supplier (Bouwcenter Logus De Hoop), where they are bundled and transported to the finishing factory every 4 to 5 houses (8 to 10 units). The amount of transportation needed is known in advance due to the high level of standardisation. With the introduction of consumer customisation, the amount of materials transported per replenishment can differ greatly and therefore, the amount of transportation needed per week between Bouwcenter Logus De Hoop and the finishing factory can fluctuate. The transportation between Bouwcenter Logus De Hoop and the second-tier material suppliers of gypsum board and metal profiles is less fluctuating since the materials needed at the finishing factory are sourced from the local inventory of Bouwcenter Logus De Hoop and fluctuations in demand are coped with by their large inventory replenished based on a safety stock. If the finishing factory would order their materials directly at the second-tier materials suppliers, the transportation would be significantly impacted since the buffer at Bouwcenter Logus De Hoop is then lost.

Technical systems

Currently, the technical systems are completely standardised for the consumer. This means that for every house in the order of the customer, the technical systems are completely the same. The result of this is that the logistical process is very predictable and an anticipatory logistical system is used where a forecast is made for the components needed and sub-components are ordered and placed in an inventory until needed. With the repositioning of the CODP, more customisation is introduced. This means that the demand is more difficult to predict and forecasting will be less effective. The anticipatory logistical system will therefore be less efficient. The fluctuation in demand for the components and subcomponents however is limited since the choice options for the consumer are not fully open. Since the technical systems are best offered in choice sets where all the components are pre-engineered. These pre-engineered components can now, up to a certain extent, be forecasted since demand can only fluctuate between the sets and not between every sub-component.

Location

Most of the needed sub-components for the technical systems come from Bouwcenter Logus De Hoop located very close to the finishing factory. The Sub-components needed for the floor heating however are sourced from a different supplier. The floor heating is sourced from Magnum Heating located in Tholen (80 kilometers away from CascoTotaal). Even though Bouwcenter Logus De Hoop is located favourable with regards to the finishing factory of CascoTotaal, the location of Magnum Heating is less favourable since for the one sub-component of the technical systems, a completely different supply line is needed.

In the new situation where the consumer is given more influence in the type of technical systems installed in the house, fluctuations in demand will be more common. Especially if the location of the supplier is further away from the finishing factory, as is the case for Magnum Heating, this will influence the ability for a long-term relationship between the finishing factory and the supplier.

Another logistical effect determined by the choice of supplier location is the assortment of the current and possible future suppliers. In the proposed level of customisation based on the most feasible positioning of the CODPs, more choice options are included in the technical systems based on a pre-engineered set of technical components. However, for the current situation with exception of the floor heating, only the assortment of Bouwcenter Logus De Hoop as preferred supplier is incorporated in the technical systems sub-components. In order to give a full range of options required to achieve the preffered level of customisation, it is seen that the current assortment of Bouwcenter Logus De Hoop is not sufficient since the sub-component of the floor heating in the current process are not sourced from them. It is therefore questionable if the assortment of Bouwcenter Logus De Hoop is sufficient in order to create the pre-engineered set of technical systems choices for the consumer. If these sets cannot be composed from the current assortment of Bouwcenter Logus De Hoop, other supplier will need to be included for the technical systems and as seen with Magnum Heating, these suppliers are mostly located further away from the finishing factory which will degrade the possibility for long-term relationships. A second possibility would be to strengthen the long-term relationship with Bouwcenter Logus De Hoop and increase their assortment of technical systems sub-components in order to create the pre-engineered sets of technical systems required. But this will increase the dependency on one single supplier for the entire process.

Inventory
Currently, the inventory is divided into two types based on their value. The low value inventory components have a local inventory at the finishing factory which is replenished when the stock level is below a certain minimum. The high value inventory items are stocked at the supplier and delivered just-in-time (once a week) at the finishing factory based on the needed amount determined by the final design. If the positioning of the CODP is shifted towards more customisation, the inventory management of the supplier will be more critical since the demand in high value components will see more fluctuation based on the chosen set of components by the consumer. This means that the information flow between the finishing factory and the suppliers needs to be optimised in order to cope with the fluctuations in materials needed. Also, the replenishing of locally stocked low value components will see more fluctuation since the amount of materials needed per house can differ. This also means that the local inventory management at the finishing factory needs to be optimised on order to trace how much materials are used per unit or house.

Transportation
In the current situation, due to the high degree of standardisation, the transportation between the suppliers and CascoTotaal is optimised so that the finishing factory is replenished once a week (just-in-time) based on the production planning. The suppliers can also easily forecast the demand since the amount of fluctuation in the sub-components needed in the final products is very minimal. The finishing factory is replenished from the two supplier locations. The result is that, once a week, two transportation movements to and two transportation movements from the finishing factory happen. The replenishing component movements for Bouwcenter Logus De Hoop are combined with other module components needed that week. However, the component movements from Magnum Heating are purely for the components needed for the floor heating.
In the new situation, the replenishing of the finishing factory is more subject to fluctuations in demand. For the replenishing from Bouwcenter Logus De Hoop these fluctuations in demand can be equalised by combining the replenishing transportation movements with the components needed for other modules. However, the transportation movements between Magnum Heating and the finishing factory are less able to equalise the fluctuations in demand since the only components transported are for the floor heating sub-components. A fixed replenishing moment by Magnum Heating is also less favourable in fluctuating demands since it is located on the other side of the Western Scheldt, which means that replenishing of the finishing factory is costlier since tolls have to be calculated for every trip to and from the finishing factory of CascoTotaal at the Western Scheldt tunnel or at the Liefkenshoek tunnel. With the fluctuations in demand, these extra logistical transportation costs cannot be divided equally over all the production units that week since the number of products needed for every week will be different based on the consumer choice of technical systems package. This can mean, that the replenishment moments have to shift because the transportation is not feasible for the amount of materials needed that week. A more optimized planning in replenishment moments based on the amount of materials needed per unit should therefore be created, or a more local distributor of the product should be used in order to transform the logistical system more towards a reactive system based on actual sales since forecasting sales is too difficult.

Interior finish

In the current production process, the logistical system used for the interior finish module is separated per component. Since the ceiling finish in every house is standardised, the logistical system used is an anticipatory system where there is a local inventory replenished based on forecasted sales. For the interior floor finishing and interior wall finishing, the tiling is chosen by the consumer and order according to actual sales in a reactive logistical system. However, as seen in the gap analysis, the amount of interior finishing needs to increase and be more consumer oriented. This means that the possibilities to forecast the components needed for the interior finish will be harder and fluctuations in demand will increase. Therefore, the anticipatory system is less effective when customisation is introduced.

Location

At the moment, all the sub-components (materials) needed for the construction of the components that make up the interior finish are sourced froma single supplier (Bouwcenter Logus De Hoop). However, Bouwcenter Logus De hoop does not have a specialised assortment of products for the interior finish since Bouwcenter Logus De Hoop is focussed on the larger quantities of materials. The assortment for the ceiling finishes is divers, however, when it comes to the Floor finishing, they only supply tiling and a limited range of other flooring finishes but for example no carpet or hardwood flooring. The same is true for the interior wall finishing, the current assortment only offers a large amount of choice in tiling and stucco interior wall finishes but very limited amount of choices in wallpaper. This means that, the assortment of Bouwcenter Logus De Hoop is limiting choices possible. In the new CODP positioning, the amount of customisation features offered to the consumer should increase throughout the interior finish module and components. This means that the current assortment of Bouwcenter Logus De Hoop is not sufficient. Other suppliers for the interior finish sub-components are therefore needed in order to offer the preferred level of customisation. Since Bouwcenter Logus De Hoop is also the supplier of other modules, the long-term relationship between the finishing factory and Bouwcenter Logus De Hoop can be an advantage. However, as determined during the interview conducted at Bouwcenter Logus De Hoop, they are willing to expand their inventory if the order quantity of the sub-components is large enough. At the moment, the location of Bouwcenter Logus De Hoop being right next to the finishing factory is an ideal location for the expansion of long-term relationships, and the willingness to expand their assortment to cope with the new demand when customisation is expanded can be seen as one of the advantages of this long-term relationship.

Inventory

Currently, there is fluctuation in the products needed, but number of products needed per week is always stable since every unit is finished with the same number and amount of sub-components, only the sub-components themselves change. The replenishment of the finishing factory its local inventory is planned according to the production planning at the start of the process and can be easily forecasted. The number of customisation features for the interior layout are limited to just a few sub-components per component of the interior layout, the forecasting is straightforward and any fluctuations in demand can be equalised by the large inventory of Bouwcenter Logus De Hoop. However, in the new process the number of sub-components to choose from by the consumer increase significantly. This means that more sub-component suppliers are required, and even if Bouwcenter Logus De Hoop is

expanding their assortment, these new products will increase the total fluctuation of sub-component demand. The more customisation features offered to the consumer, the more fluctuation in these features will be translated to the sub-components needed. These fluctuations also make the forecasting for the number of sub-components harder, therefore, the total logistical system to be used should be transformed into a reactive system where the sub-components are only ordered once they are chosen in the final design. This means that the final design of the interior layout will become a critical point in the information process.
However, not only fluctuations in demand will influence the inventory, more demand in general will also be the result of the new process. In the new process, the number of customisation features offered is not only increasing, also the amount of finishing within the final product increases. At the moment, the amount of interior finishing is very minimal. From the process effects, it was seen that introducing more interior finishing in the final unit, the impact on the consumer satisfaction is relatively high when compared to other modules. Therefore, in the gap analysis a situation was created where in the interior finishing, all the walls, ceilings and floors could be finished. This means that the amount of materials needed for the production of the interior finish component will increase and therefore, with the current replenishing schedule, the amount of local inventory at the finishing factory of will increase significantly. But, the amount of space available at the finishing factory for inventory per product module is very limited. The space currently available is not sufficient to keep the required inventory when the replenishing schedule is kept at once a week for 4 to 5 houses (8-10) units. This can be solved with more replenishing moments, but this will influence the transport factor of the logistical process.

Transportation
The transportation factor of the interior layout for the process of CascoTotaal is highly influenced by the inventory factor. The main reason for this is that the first-tier module supplier is so close to the finishing factory, that transportation between these two is almost negligible. However, for the interior finish module, the proposed changes are so significant, the transportation factor of the logistical system is also impacted.
Currently, all the needed sub-components are transported from the second-tier suppliers to Bouwcenter Logus De Hoop where they are stored in a large general inventory. From this large general inventory, the needed (ordered) sub-components are transported once a week together with other sub-components of other product modules to the finishing factory according to the production planning. However, in the new logistical system, Bouwcenter Logus De Hoop said they are willing to create a specific inventory for the products not in the standard assortment. This means that if the interior finish customisation features are expanded, more second-tier suppliers are incorporated in the logistical system and more transportation to and from Bouwcenter Logus De Hoop is created in order to replenish this special inventor. Depending on the locations of these second-tier suppliers, this can have a significant impact on the total transportation factor. With regards to the replenishing transportation between Bouwcenter Logus De Hoop and the finishing factory, the once a week replenishing of the local inventory of the finishing factory is no longer possible due to the increase in number of sub-components needed. This means that the schedule for the replenishing needs to be adjusted. The effect of this on the logistical transportation factor is that more frequent transportation movements are needed between Bouwcenter Logus De Hoop and the finishing factory. The logistical planning will therefore become more critical in the entire process.

Exterior finish

In the current process for the exterior finish, the customer is the decider. This means that in the early stages of the project all the critical components of the exterior finish are known. The logistical process for the entire exterior finish module is therefore set up as reactive. Once the design stages after the sale to the customer are complete the order processes of the needed sub-components is started. This can be realised since the consumer has no influence on the exterior finish so even when the final design is not already composed together with the consumer, the basic design will not change. In the new situation, the consumer does have influence on the final exterior finish of the house, but the critical engineering components will stay the same. The number of sub-components needed for the production process can be forecasted once the houses are sold since the amount of sub-components does no longer change. However, the construction process has not yet started in order to be reactive. For the components of exterior roof finish and exterior wall finish, the logistical process will be reactive since the consumer can chose these in the later stages of the process. The process will have to be reactive since the amount of customisation features offered to the consumer, as specified in the gap analysis, cannot all be stocked and therefore, the sub-components can only be ordered once the design is finalised.

Location

Currently, there are multiple physical supplier locations for the components of the exterior finish module. As seen in other modules, Bouwcenter Logus De Hoop is the main supplier of the components and located very close to the finishing factory. The exterior roof finish and the window and doorframes components are supplied by Bouwcenter Logus De Hoop from their local inventory. However, the insulation and exterior wall finish components in the current process are delivered to the factory directly from their second-tier materials supplier. However, in the current process, the location and relationship between CascoTotaal and Bouwcenter Logus De Hoop is proven to not be a limiting factor. Earlier in the logistical analysis it was suggested that Bouwcenter Logus De Hoop is willing to expand their assortment for the needs of the finishing factory. This is proven by the exterior finishing module since for the current process, Bouwcenter Logus De Hoop cooperated with CascoTotaal in order to expand their assortment to suit the needs of CascoTotaal. This meant that the current assortment is expanded especially for CascoTotaal for the insulation and exterior wall finish components. However, this will have a negative effect on the logistical process since the price of the services offered by Bouwcenter Logus De Hoop, purchase from and negotiations with second-tier materials suppliers will increase the total logistical costs.

Inventory

Currently, the amount of materials needed can be forecasted based on the number of houses sold to the customers. This means that the inventory control of the finishing factory can be based on the forecast and replenished accordingly. The local inventory of the finishing factory is the only inventory of the exterior wall finish which is replenished directly from the second-tier materials supplier. In the current process, this is Feldhaus Klinker in based in Germany (Bad Laer) who produces the brick slips used according to the specifications of the customer in batches of 1000m^2. This means that the replenishment takes place every 16 to 17 houses (32 to 34 units) with the average exterior wall finish of a unit is around 30m^2. For the insulation, the replenishment of the extruded polystyrene (XPS) panels used also happens directly from the second-tier material supplier (Easylationwall) its production facility in Volkel, The Netherlands. The replenishing of the insulation panels and included hardware needed for installation currently happens per full truckload ($400m^2$). With an average of $30m^2$ needed per unit the replenishment of the local inventory at the finishing factory takes place every 6 to 7 houses (12 to 14 units).

In the new most feasible CODP position, the amount of customisation for the consumer will increase. However, as determined in the gap analysis the technical components: the insulation and the window- and doorframes will still be determined by the customer. Only the components: exterior roof finish and exterior wall finish are transferred in limited amounts to the consumer. The consumer is given a choice based on a by the customer determined choice set (for the determination of the logistical effects, a brick slip exterior wall finish is used).

In the new situation, the final decision on the exterior roof- and wall finish is left to the consumer within a predetermined range. This will have a significant impact on the inventory levels, mainly created by the fluctuations in demand when shifting the decision point further towards the consumer and increasing the difficulty to forecast demand. For the technical components (insulation and window- and doorframes) there is no shift in CODP since the decision point stays at the customer. Therefore, the current logistical system is sufficient. However, for the roof finish, the inventory of Bouwcenter Logus De Hoop needs to be able to cope with the increase fluctuations in demand. The same is not true for the exterior wall finish, the components of the exterior wall finish are replenished in batches of 16 to 17 houses and every extra choice in exterior wall finish will increase the local inventory needed since smaller batches are not produced by the current supplier. Now there are two options possible: switch to another supplier (the option of switching to another supplier can also be compared to incorporating an entirely different exterior finish such as artificial wood panels) or reorganise the logistical process for the current supplier.

If a different supplier is chosen, the logistical location factor is also impacting the process besides the inventory factor. It is therefore advisable to search for a different supplier within the current range of exterior finish suppliers from Bouwcenter Logus De Hoop since this would have a positive effect on the long-term relationship and can simplify the entire logistical implications. The current possibilities within the assortment of Bouwcenter Logus De Hoop are sufficient enough to provide the required level of customisation and other materials besides brick slips would also be a possibility to offer to the consumer. The created fluctuations in demand can now also be equalised using the large inventory of Bouwcenter Logus De Hoop. In the second option of reorganising the logistical process, the logistical effects on the inventory are far more significant. Besides not being able to introduce different exterior finishes, the inventory at the finishing factory would need to expand in order to cope with the fluctuations in demand. For example, if three different types of brick slips are offered to the consumer to choose from. The inventory at the start of the process would grow to 3000 m^2 of brick slips being stored at the finishing factory since every type has to be ordered in a minimum quantity of 1000 m^2. This is equivalent to the amount used on 50 houses (100 units). The limited storage space at the finishing factory of CascoTotaal would not be able to cope with this amount of inventory besides the effects on the inventory value being added to the process costs. The alternative would be to change the inventory location to Bouwcenter Logus De Hoop who would act as an intermediate inventory until the products are needed at the finishing factory and deliver them just-in-time according to the production schedule.

Transportation
As seen previously, the components; insulation and exterior wall, even though the supplier is Bouwcenter Logus De Hoop on paper, are directly transported from their second-tier supplier to the finishing factory. This means more inventory is held at the finishing factory, however, for the transportation required in the whole process this is an advantage since no intermediate transportation is needed between the first- and second-tier materials suppliers. For the other components, these are replenished from the inventory of Bouwcenter Logus De Hoop every week based on the production planning. As seen in the inventory factor, the introduction of more customisation features can have a significant impact on the inventory placement of the needed sub-components. Two situations were discussed, however, in both situations, the result on the transportation factor are comparable. In both situations, the inventory of Bouwcenter Logus De Hoop will function as an intermediate storage in order to fulfil the minimum order quantity required by the second-tier supplier or in order to cope with the newly created fluctuations in demand. In both situations, the amount of transportation needed between Bouwcenter Logus De Hoop and the finishing factory will increase significantly to replenish the local inventory of the finishing factory. A second effect on the transportation is the increase of transportation movements between the second-tier material suppliers and Bouwcenter Logus De Hoop as first-tier material supplier. This increase is due to the increased amount of sub-component options offered to the consumer which have to be transported. An example of this is found in the brick slips since these are produced in batches of 1000 m^2 per type, every increase in type of brick slips will show in an extra transportation movement to and from the second-tier material supplier and Bouwcenter Logus De Hoop. However, when this is compared to the traditional building site. The transportation is reduced to low populated areas since all suppliers are located in low populated industrial areas. If the same amount of customisation would be introduced on a traditional construction site, the transportation movements would all happen in more densely populated areas.

Kitchen and bathroom
Since the sub-components used in the kitchen and bathroom are very similar and also the logistical impact is comparable, these two modules are combined into one section where the difference in production method highlights the logistical impact.
In the current process, both the kitchen and the bathroom have reactive logistical processes since consumer input is needed in order to start the construction process as seen in the SCOR model thread diagram where both the kitchen and the bathroom module are made-to-order with a make step at the first-tier material supplier. This is because the current process already includes a relatively high level of customisation. From the gap analysis, it became clear that the level of customisation can be increased by offering more customisation features to the consumer in the sub-components.

Location
The first tier-supplier of both the bathroom and kitchen is Logus, which has multiple showroom locations in the south-eastern part of The Netherlands (Terneuzen, Oostburg, Vlissingen, Goes, Bergen op Zoom, Roosendaal and Zwijndrecht). These locations are used to invite the consumer to choose the customisation features offered in both the kitchen and bathroom. The chosen options are collected by the different showrooms and communicated to kitchen factory and constructed into sub-assemblies according to the specifications of the

consumer. These subassemblies are then transported to the finishing factory of CascoTotaal and installed in the final unit. For the bathroom, the options are also collected at the different showrooms but, the sub-components needed for the construction of the bathroom are then collected by Bouwcenter Logus De Hoop and bundled per house into pallets to be delivered to the finishing factory where they are used to construct the bathroom. However, for both the kitchen and the bathroom, the assortment of Logus is the limiting factor in the options that can be offered to the consumer. However, with the current assortment of Logus, the required level of customisation can easily be attained since the assortment includes most requested brands of kitchen and bathroom components as was extracted from the interview at Logus De hoop.

Inventory

The main difference between the bathroom and the kitchen is found in the placement of inventory. Since both modules have a responsive logistical system where sub-components are only ordered once the final design is approved by the consumer. For the kitchen, it is constructed in a different factory where their inventory is used to construct multiple kitchens at the same time for different customers. This means that the inventory management is completely left to the kitchen factory and the sub-assemblies that are used at the finishing factory of CascoTotaal are delivered just-in-time and only shortly stored before they are installed in the unit. For the bathroom, this is different since the bathrooms are constructed inside the final unit in the finishing factory from sub-components, therefore in order to be able to cope with the fluctuating demand introduced by customisation, the inventory at the first-tier supplier should be sufficient to cope with this. Besides this, there are multiple sub-components stored in the inventory of the finishing factory in order to be able to construct the bathroom on time which all have separate transportation movements.

Transportation

Both the kitchen and the bathroom module require transportation from the first-tier material supplier to the finishing factory. However, for the kitchen these transportation movements consist of sub-assemblies (components) while for the bathroom, these are on the sub-components level. This means that if more customisation is added to both modules, the kitchen transportation effects are not impacted because, the kitchen supplier already has the needed materials in stock and only the assembly or construction process will be different. But, for the bathroom, since it is constructed in the finishing factory, it means that the transportation factor is impacted. The sub-components needed for the bathroom are transported from different second-tier suppliers to the first-tier supplier (Bouwcenter Logus De Hoop). If the amount of customisation features increases, this means that more second-tier suppliers need to transport their materials to Bouwcenter Logus De Hoop. Bouwcenter Logus De Hoop will then combine the different needed sub-components into per house pallets and transport these to the finishing factory of CascoTotaal. The transportation impact of the logistics is therefore visible in the amount of transportation between the first- and second-tier suppliers where an increase in customisation features results in an increase in transportation movements while for the kitchen even though the amount of customisation is very similar, due to the construction process, the amount of transportation impact will stay the same.

Appendix VII Housing components points table

(Huurcommissie, 2016)

Housing component	Eligible Points
Quarter square space *(living rooms, bedrooms, kitchens, bathrooms/showers)*	1 point per m^2
Other quarter square space	0,75 point per m^2
Heating *Per heated quarter* *Per other quarter* * maximum of 4 points	 2 points 1 point*
Energy efficiency *Label A++* *Label A+* *Label A* *Label B* *Label C* *Label D* *Label E* *Label F* *Label G*	 44 points 40 points 36 points 32 points 22 points 14 points 8 points 4 points 0 points
Energy neutral house *(only eligible if an agreement between renter and tenant has been setup in advance) (no Energy efficiency points are counted)*	32 points
Kitchen *Length of countertop <1m* *Length of countertop 1 till 2 m* *Length of countertop >2m* * points can be doubled when extra quality features are added (per 226,89 euro investment, 1 extra point can be counted)	 0 points 4 points 7 points*
Bathroom *Toilet* *Washbasin* *Shower* *Bathtub* *Bathtub/Shower combination* * points can be doubled for extra quality features (per 226,89 euro investment, 1 extra point can be counted)	 3 points 1 point 4 points 6 points 7 points*
Property valuation (WOZ)* Per 7995 euro Property valuation divided by square space, per 122 euro *The minimum property value is 40,480 euro even when the actual property value is lower	 1 point 1 point** ** For new houses in the private rent sector, a minimum of 40 points needs to be taken
Care facilities for disabled people (only for special needs housing) Per 226.89 euro of extra features	1 point
Special needs (only eligible for care home)	35% of all previous points added together

In order to convert the calculated points from the previous table into a maximum amount of rent the housing association or developer can ask from the consumer the following table is used:

(Huurcommissie, 2017)

punten	bedrag	punten	bedrag	punten	bedrag	punten	bedrag	punten	bedrag
40	189	**82**	388,27	**124**	606,08	**166**	823,84	**208**	1041,63
41	193,72	**83**	393,46	**125**	611,26	**167**	829,02	**209**	1046,81
42	198,44	**84**	398,63	**126**	616,43	**168**	834,2	**210**	1052,02
43	203,16	**85**	403,84	**127**	621,61	**169**	839,42	**211**	1057,18
44	207,88	**86**	409,03	**128**	626,84	**170**	844,59	**212**	1062,36
45	212,59	**87**	414,2	**129**	631,97	**171**	849,77	**213**	1067,55
46	217,34	**88**	419,39	**130**	637,18	**172**	854,95	**214**	1072,73
47	222,05	**89**	424,56	**131**	642,36	**173**	860,15	**215**	1077,92
48	226,79	**90**	429,77	**132**	647,53	**174**	865,31	**216**	1083,1
49	231,51	**91**	434,94	**133**	652,74	**175**	870,51	**217**	1088,3
50	236,23	**92**	440,11	**134**	657,91	**176**	875,69	**218**	1093,47
51	240,92	**93**	445,32	**135**	663,12	**177**	880,87	**219**	1098,66
52	245,68	**94**	450,49	**136**	668,27	**178**	886,07	**220**	1103,87
53	250,38	**95**	455,68	**137**	673,48	**179**	891,25	**221**	1109,02
54	255,12	**96**	460,86	**138**	678,67	**180**	896,41	**222**	1114,22
55	259,84	**97**	466,07	**139**	683,83	**181**	901,63	**223**	1119,4
56	264,59	**98**	471,24	**140**	689,02	**182**	906,81	**224**	1124,59
57	269,26	**99**	476,44	**141**	694,23	**183**	911,99	**225**	1129,76
58	273,99	**100**	481,61	**142**	699,38	**184**	917,16	**226**	1134,96
59	278,74	**101**	486,79	**143**	704,56	**185**	922,37	**227**	1140,14
60	283,47	**102**	491,97	**144**	709,77	**186**	927,56	**228**	1145,33
61	288,16	**103**	497,17	**145**	714,97	**187**	932,73	**229**	1150,53
62	292,91	**104**	502,36	**146**	720,13	**188**	937,93	**230**	1155,7
63	297,61	**105**	507,52	**147**	725,33	**189**	943,1	**231**	1160,87
64	302,34	**106**	512,73	**148**	730,51	**190**	948,29	**232**	1166,08
65	307,06	**107**	517,91	**149**	735,7	**191**	953,49	**233**	1171,26
66	311,8	**108**	523,08	**150**	740,87	**192**	958,65	**234**	1176,43
67	316,52	**109**	528,28	**151**	746,06	**193**	963,85	**235**	1181,63
68	321,23	**110**	533,47	**152**	751,24	**194**	969,05	**236**	1186,81
69	325,94	**111**	538,66	**153**	756,43	**195**	974,23	**237**	1192
70	330,67	**112**	543,83	**154**	761,61	**196**	979,38	**238**	1197,17
71	335,39	**113**	549,01	**155**	766,8	**197**	984,58	**239**	1202,37
72	340,13	**114**	554,22	**156**	771,97	**198**	989,78	**240**	1207,55
73	344,83	**115**	559,4	**157**	777,2	**199**	994,95	**241**	1212,74
74	349,57	**116**	564,57	**158**	782,34	**200**	1000,15	**242**	1217,93
75	354,29	**117**	569,76	**159**	787,56	**201**	1005,32	**243**	1223,1
76	359,03	**118**	574,94	**160**	792,73	**202**	1010,51	**244**	1228,3
77	363,73	**119**	580,12	**161**	797,91	**203**	1015,69	**245**	1233,49
78	368,48	**120**	585,31	**162**	803,11	**204**	1020,88	**246**	1238,66
79	373,18	**121**	590,51	**163**	808,27	**205**	1026,07	**247**	1243,82
80	377,92	**122**	595,7	**164**	813,46	**206**	1031,25	**248**	1249,05
81	383,08	**123**	600,87	**165**	818,65	**207**	1036,46	**249**	1254,22
								250	1259,39

Appendix VIII Spero 1 Base situation for market repositioning

For the calculations of the market repositioning based on customisation features offered a base situation for the Spero 1 single family home is created. This base situation is taken from an example design made by CascoTotaal as found below.

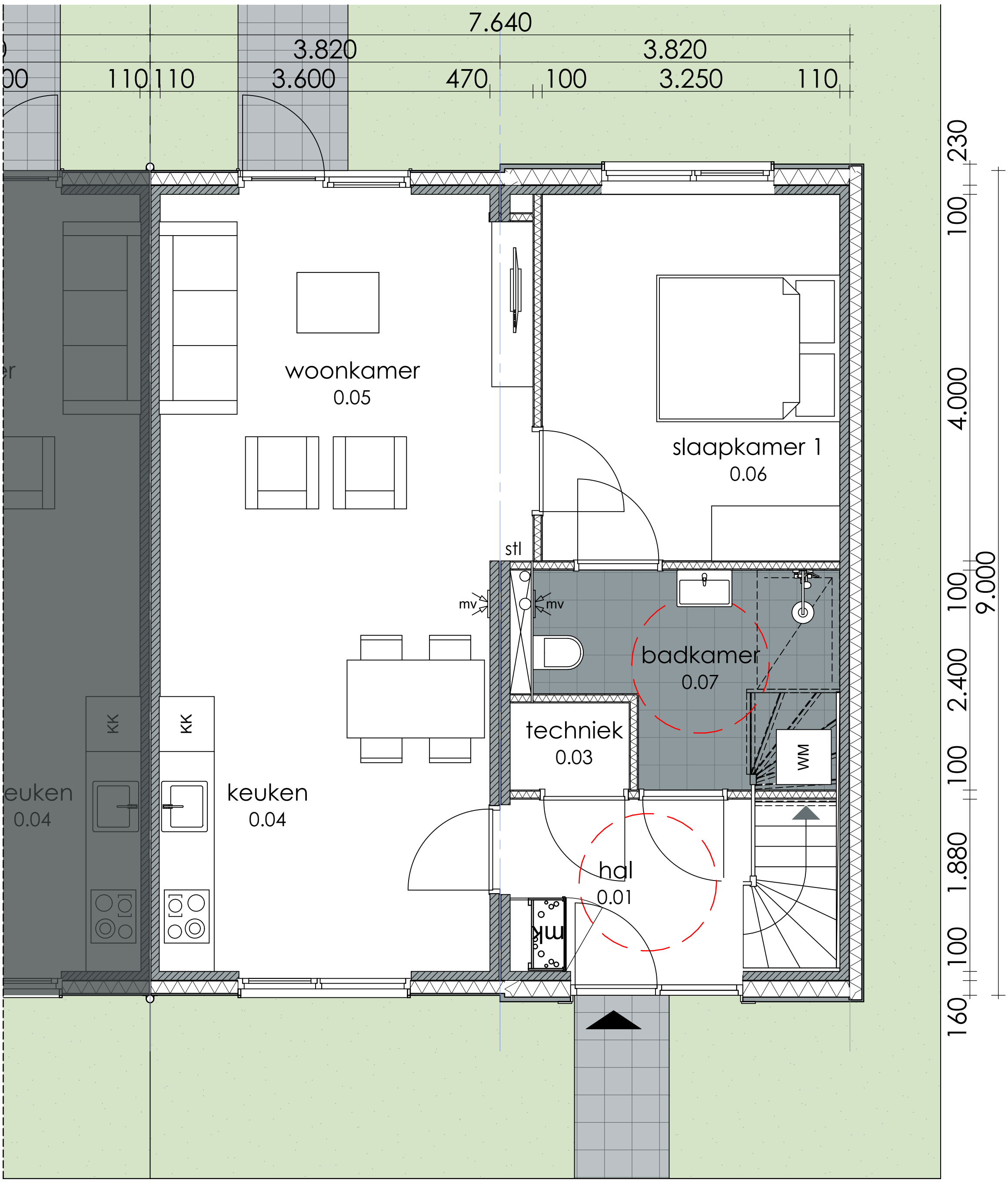


Figure 64: Spero 1 base situation ground floor

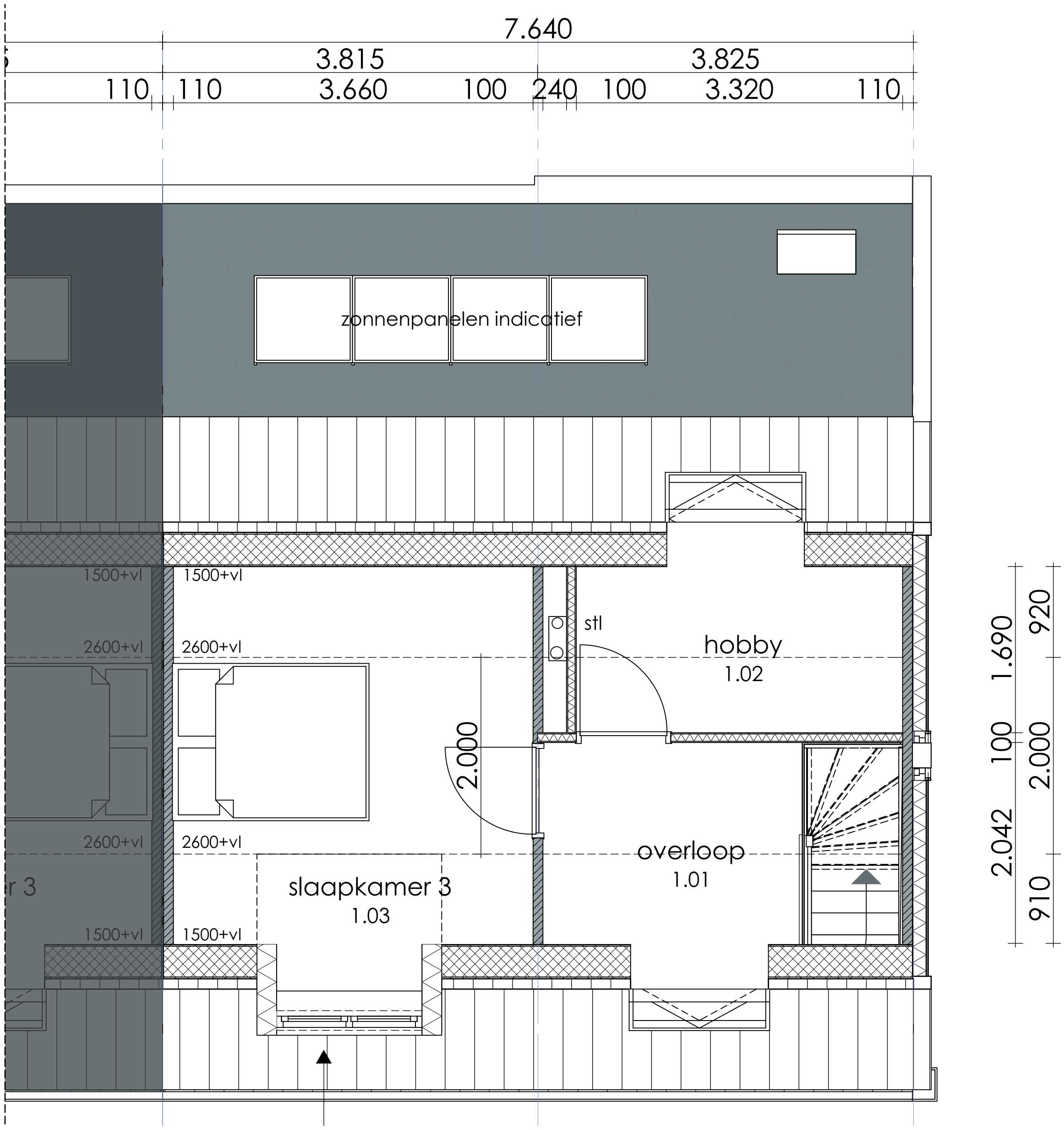


Figure 65: Spero 1 base situation top floor

Appendix IX Points awarded to the Spero 1 house

Table 14: Awarded points for social housing composition

Housing component	Eligible Points	Points awarded
Quarter square space *(living rooms, bedrooms, kitchens, bathrooms/showers)*	1 point per m^2	75
Other quarter square space (not including hallways)	0,75 point per m^2	-
Heating *Per heated quarter* *Per other quarter* * maximum of 4 points	 2 points 1 point*	 12 0 12
Energy efficiency *Label A++* *Label A+* *Label A* *Label B* *Label C* *Label D* *Label E* *Label F* *Label G*	 44 points 40 points 36 points 32 points 22 points 14 points 8 points 4 points 0 points	 44 (In case of an energy neutral house with an agreement this can be 0)
Energy neutral house *(only eligible if an agreement between renter and tenant has been setup in advance) (no Energy efficiency points are counted)*	32 points	(32 if an agreement is made in advance, otherwise 0)
Kitchen *Length of countertop <1m* *Length of countertop 1 till 2 m* *Length of countertop >2m* * points can be doubled when extra quality features are added (per 226,89 euro investment, 1 extra point can be counted)	 0 points 4 points 7 points*	 7
Bathroom *Toilet* *Washbasin* *Shower* *Bathtub* *Bathtub/Shower combination* * points can be doubled for extra quality features (per 226,89 euro investment, 1 extra point can be counted)	 3 points 1 point 4 points 6 points 7 points*	 3 1 4 - - 8
Property valuation (WOZ)* Per 8,259 euro Property valuation divided by square space, per 127 euro *The minimum property value is 40,480 euro even when the actual property value is lower	 1 point 1 point** ** For new houses in the private rent sector, a minimum of 40 points needs to be taken	 15,74 13,65 29,39 = 29
Care facilities for disabled people (only for special needs housing) Per 226.89 euro of extra features	1 point	-
Special needs (only eligible for care home)	35% of all previous points added together	-
TOTAL POINTS AWARDED		**175 or 163**

Table 15: Awarded points for non-energy neutral Spero 1 house

Housing component	Eligible Points	Minimum	Maximum
Quarter square space *(living rooms, bedrooms, kitchens, bathrooms/showers)*	1 point per m^2	75	75
Other quarter square space (not including hallways)	0,75 point per m^2	-	-
Heating *Per heated quarter* *Per other quarter* * maximum of 4 points	 2 points 1 point*	 12 0 12	 12 2 14
Energy efficiency *Label A++* *Label A+* *Label A* *Label B* *Label C* *Label D* *Label E* *Label F* *Label G*	 44 points 40 points 36 points 32 points 22 points 14 points 8 points 4 points 0 points	 44	 44
Energy neutral house *(only eligible if an agreement between renter and tenant has been setup in advance) (no Energy efficiency points are counted)*	32 points	-	-
Kitchen *Length of countertop <1m* *Length of countertop 1 till 2 m* *Length of countertop >2m* * points can be doubled when extra quality features are added (per 226,89 euro investment, 1 extra point can be counted)	 0 points 4 points 7 points*	 7	 7 7 luxury 14
Bathroom *Toilet* *Washbasin* *Shower* *Bathtub* *Bathtub/Shower combination* * points can be doubled for extra quality features (per 226,89 euro investment, 1 extra point can be counted)	 3 points 1 point 4 points 6 points 7 points*	 3 1 4 - - 8	 3 2 - - 7 12 12 luxury 24
Property valuation (WOZ)* Per 8,259 euro Property valuation divided by square space, per 127 euro *The minimum property value is 40,480 euro even when the actual property value is lower	 1 point 1 point** ** For new houses in the private rent sector, a minimum of 40 points needs to be taken	 15,74 13,65 29,39 = 29 private sector 40	 15,74 13,65 29,39 = 29 private sector 40
Care facilities for disabled people (only for special needs housing) Per 226.89 euro of extra features	1 point	-	-
Special needs (only eligible for care home)	35% of all previous points added together	-	-
TOTAL POINTS AWARDED		**186**	**211**

Table 16: Awarded points for energy neutral Spero 1 house

Housing component	Eligible Points	Minimum	Maximum
Quarter square space *(living rooms, bedrooms, kitchens, bathrooms/showers)*	1 point per m^2	75	75
Other quarter square space (not including hallways)	0,75 point per m^2	-	-
Heating *Per heated quarter* *Per other quarter* * maximum of 4 points	 2 points 1 point*	 12 0 12	 12 2 14
Energy efficiency *Label A++* *Label A+* *Label A* *Label B* *Label C* *Label D* *Label E* *Label F* *Label G*	 44 points 40 points 36 points 32 points 22 points 14 points 8 points 4 points 0 points	-	-
Energy neutral house *(only eligible if an agreement between renter and tenant has been setup in advance) (no Energy efficiency points are counted)*	32 points	32	32
Kitchen *Length of countertop <1m* *Length of countertop 1 till 2 m* *Length of countertop >2m* * points can be doubled when extra quality features are added (per 226,89 euro investment, 1 extra point can be counted)	 0 points 4 points 7 points*	7	7 7 luxury 14
Bathroom *Toilet* *Washbasin* *Shower* *Bathtub* *Bathtub/Shower combination* * points can be doubled for extra quality features (per 226,89 euro investment, 1 extra point can be counted)	 3 points 1 point 4 points 6 points 7 points*	 3 1 4 - - 8	 3 2 - - 7 12 12 luxury 24
Property valuation (WOZ)* Per 8,259 euro Property valuation divided by square space, per 127 euro *The minimum property value is 40,480 euro even when the actual property value is lower	 1 point 1 point** ** For new houses in the private rent sector, a minimum of 40 points needs to be taken	 15,74 13,65 29,39 = 29 private sector 40	 15,74 13,65 29,39 = 29 private sector 40
Care facilities for disabled people (only for special needs housing) Per 226.89 euro of extra features	1 point	-	-
Special needs (only eligible for care home)	35% of all previous points added together	-	-
TOTAL POINTS AWARDED		**174**	**199**