Smart Renovation Factory by INDU-ZERO

Interreg North Sea Region INDU-ZERO
European Regional Development Fund

EUROPEAN UNION

SAXION

Cost reduction for construction site assembly and outbound logistics for renovations with INDU-ZERO

Martijn Gervedink Nijhuis | University of applied sciences Saxion Enschede

25-10-2021

Document:	Thesis
Date:	25-10-2021
Internship period:	1st/2nd quarter of 2021

School:	Saxion University of Applied Sciences
Academy:	Business, Building and Technology
Education:	Industrial Engineering & Management
Year:	4
Adress:	M.H. Tromplaan 28
Postal code:	7513 AB
City:	Enschede
Internship supervisor:	Jacques Bazen
Email:	j.c.bazen@saxion.nl
Teacher supervisor:	Martijn Kamphorst
Email:	m.g.b.kamphorst@saxion.nl

Autor:	Martijn Gervedink Nijhuis
Student number:	425632
Email:	425632@student.saxion.nl

Preface

This document contains a research for Saxion University of Applied Sciences, which describes methods and solutions for saving costs for renovating houses with INDU-ZERO and a calculation model of the costs of the processes construction site assembly and outbound logistics. Throughout this research, the term “renovation process” is used to summarize these processes.

The research is carried out before graduating from the Industrial Engineering & Management program at the Saxion University of Applied Sciences in Enschede.

I would like to thank my internship supervisor, the lecturer supervisor, the partners of the INDU-ZERO project, the employees of Saxion University of Applied Sciences and other stakeholders who helped compile this thesis.

Martijn Gervedink Nijhuis

Enschede, October 25 2021

Terms used in the research

The terms which are used in the research and in this plan are explained below.

- **Renovation process:** In the research, the term renovation process was be used to summarize the processes construction assembly and outbound logistics.
- **Construction site assembly:** The onsite assembly process is the management and culmination of all project activities used to deliver on time to the client (Supply chain school, sd). In this case, a house renovation is meant by a construction company.
- **Outbound logistics:** Outbound logistics is the process of storing, transporting and distributing goods to customers (Lopienski, 2020). In this case only transport is included.
- **Renovation packages:** Standard renovation packages that will contain components that are necessary to make homes sustainable, and consists of insulation material for walls and roofs, heat pumps, solar panels, energy converters and ventilation systems. These special renovation packages are meant to help homes in the North Sea Region (countries adjacent to the North Sea), to quickly become energy neutral and future-proof (Northsearegion, sd).
- **What-if scenario analysis:** The definition of scenario analysis is the process of considering different, possible outcomes of a decision (thefreedictionary, sd). In this research, different outcomes must be predicted because there is no process yet.
- **Schedule:** With this schedule a variable visualised schedule is meant to plan a project.
- **Project planning:** Part of project management, which relates to the use of schedules such as Gantt charts to plan and subsequently report progress within the project environment (Kerzner, 2003)**.**
- **Anchors and Shöck anchors:** Façade anchors are anchors for constructive multiple fixing or anchoring of non-load-bearing systems (Ejot, sd). In this case, anchors to fixate façades are meant. The company Shöck has anchors like these with which tasks can be done faster according to a student at Saxion (Hesselink, Definitieve keuzes, 2021) and a report by students (Jager, Kooij, Platenkamp, Temmink, & van 't Hul, 2020).
- **Scaffolding and triangle bridge:** Poles and boards that are joined together to make a structure for workers to stand on when they are working high up on the outside wall of a building (Oxford Learner's dictionaries, sd). The modular triangle bridges consist of various components that are easily assembled into a complete work bridge. The triangle bridge is easily, quickly and versatilely deployable for painters and plumbers or in façade renovation companies (Altrex, sd). It can be used as an alternative to regular scaffolding.
- **Make-or-buy decisions:** The choice between doing a process like transport yourself or outsourcing it. Make or buy strategy is used in the field of logistics activities and focuses on the creation of a number of options and to minimize logistics costs (Cieśla, 2015).
- **Six Sigma:** In 1986, Bill Smith, a senior engineer and scientist at Motorola, introduced the concept of Six Sigma to standardize the way defects are counted. Six Sigma provided Motorola the key to addressing quality concerns throughout the organization, from manufacturing to support functions (Motorola, sd). Among other methods, the DMADV framework used in this research is a six-sigma method.
- **Cost model:** A compilation of cost estimating logic that aggregates cost estimating details into a total cost estimate. An ordered arrangement of data, assumptions, and equations that permits translation of physical resources or characteristics into costs. Cost models generally consist of a set of equations, logic, programs, and input formats. (García de Soto Lastra, 2014). It is also necessary to find out how cost savings can be implemented in the cost model to achieve a result for INDU-ZERO.
- **Retrofitting:** The addition of new technology or features to older systems, like home energy retrofitting which is improving existing buildings with energy efficiency equipment (Certified energy, 2018).

Management summary

INDU-ZERO is an innovative new project developed by partners of the INDU-ZERO project and the Interreg NSR (North Sea Region) program which focuses on developing the regions of seven countries around the North Sea into areas with a strong and sustainable working and living environment. With the project, research is done on creating a realistic starting point for companies to build a factory for renovation packages which serve as materials to do renovations with a new and innovative way. This specific research focuses only on doing the actual renovations with construction site assembly and outbound logistics (renovation process). INDU-ZERO's goal is to design a factory blueprint with capacity to manufacture renovation packages suitable for all NSR countries, at a high volume and at 50% lower cost. Before this research there was clearly a missing strategy and starting point for the renovation process which consists of the processes construction site assembly and outbound logistics.

Most optimal business plan for INDU-ZERO's renovation process

This research is the most complete and optimal plan on how INDU-ZERO's renovation process is going to function in practice and what the costs will be. It contains solutions such as planning's and a cost model with a strategy for INDU-ZERO. The plan contains multifaceted analyses of cost saving methods, decisions to establish a new process and data solutions. The new methods for the renovation process include:

- New resources; new innovative ways for tasks with new equipment and tools.
- New web-based training; an additional web-based training tool can be used.
- New standardized planning methods; Strategies for a new planning have been established by experts.
- Outsourcing; decisions have been made on what needs to be outsourced.

According to the estimation made in this research, €15.415 per house can potentially be saved with the cost saving methods and new decisions. In order to implement the new process, new methods and decisions, two data solutions have been established in this research. These data solutions are:

- Planning; more standardized new planning's which conclude that the renovation process can be done in 3 days. It was developed by the researcher with information from experts.
- Cost model; a cost model was made with all the costs for INDU-ZERO's process.

Conclusion

This research concludes that for the renovation process which includes only construction site assembly and outbound logistics the cost saving potential is estimated at €15.415 per house. The total costs of INDU-ZERO's processes, which includes other processes than construction site assembly and outbound logistics is now estimated at 52% compared to the construction company's process. The current costs for the process construction site assembly has been calculated at €9.915 and the outbound logistics at €485 per house. The research proves that when using the strategy and methods for the renovation process, the costs are close to achieving INDU-ZERO's goals of reducing the costs by 50% when using the current budget.

Chapter 1: Introduction

This research is commissioned by Saxion and partners of the INDU-ZERO project. Through contact with members of the research group this research was started. The goal was cost reduction in the processes construction site assembly and outbound logistics (can be summarized in "renovation process") relative to costs for companies currently. In chapter 1, an introduction to the project is described, then the cost targets which the project aims for with its processes is described and the problem which the research needed to solve. The goal and the research questions are described after this. More background information is given in Appendix 2: 'Background information INDU-ZERO'

1.1 The research group, industrialization & the INDU-ZERO project

In paragraph 1.1 the research group, industrialisation of construction and transport and the project INDU-ZERO is described. This chapter serves as an introduction to the project.

1.1.1 Introduction to University of Applied Sciences Saxion & research group SBT

Saxion is a University of Applied Sciences for higher professional education (HBO). More than 26,000 students study at Saxion in Apeldoorn, Deventer and Enschede. Saxion arose from the rich educational history of Deventer and from the social initiatives of enterprising textile traders in Twente. Deventer has been a stronghold of books and knowledge since the 13th century. Saxion offers a variety of courses and special graduation options and specializations, both national and international. Applied research is carried out by research groups in collaboration with companies and institutions. In addition, the part-time school offers a varied range of continuing education and training (Saxion, sd). The Sustainable Building Technology (SBT) research group focuses primarily on providing methods and resources such as digital tools. In doing so, they facilitate the reduction of construction-related greenhouse gas absorption during the construction and operation phase, combat climate change and support the market power of project partners (Saxion, sd). The research group is among other projects involved, as one of the partners, in a project named INDU-ZERO.

1.1.2 Industrialization of the construction industry & standardization

The building and construction industry is often perceived as a laggard for innovation compared with other industries. The fragmentation of the industry, the procurement process mainly based on tendered price and the conservatism of employees of the building site are often put forward to explain this situation. But the construction industry is also looking for new methods, approaches and tools that will improve its performance. Industrialisation, prefabrication, concurrent engineering, supply chain management and clients' participation have been considered as ways for the industry to improve its practices. The concept of industrialisation mainly concerns the suppliers of the construction industry who provide standardized and industrialised products (Bougrain, Forman, & Huagbølle, 2010). During the period following World War 2

several initiatives were launched to promote industrialisation in construction. For example in France these attempts resulted from the demand of the State that guaranteed the construction of thousands of social housings. In the Netherlands present-day, tools such as BIM and Lean are used for building new houses (Randewijk, sd). However, there is need for a more industrialized and standardized approach for renovating to energy efficient houses. When renovating houses, every house is different and renovation packages and activities need to be adjusted for every house. Renovations are currently too slow in the North Sea region and the costs are too high (Northsearegion, sd). For this reason, there is a huge demand for a more industrialized, standardized and more efficient approach for renovating the houses with insulation material for walls and roofs, heat pumps, solar panels, energy converters and ventilation systems in terms of transport and assembly. Newer techniques, methods or plans can possibly be implemented for standardized houses.

1.1.3 Project INDU-ZERO (Smart Renovation Factory)

INDU-ZERO is a project that develops a blueprint for an innovative factory that will be able to produce 15.000 renovation packages per year for half of the current market price including logistics and assembly on the construction site. The specific cost target will be described in sub-paragraph 1.2.2. A blueprint is an early plan or design that explains how something might be achieved (Cambridge, sd). The renovation packages will consist of sustainable net Zero renovation packages for existing houses. The standard packages can be applied to terraced houses and apartments built between 1950 and 1985 (Northsearegion, sd). They can also be used for modern houses, but those houses are usually already better isolated. Older houses, built before 1950 are harder to renovate because they are built less standardized and/or may have monument status, making individually tailored approaches necessary. The blueprint for this factory, also called a smart renovation factory, will be available to all factory developers (Housing evolutions, sd). With renovation in this research retrofitting houses to near energy neutral houses is meant.

1.2 Motive and problem definition

The problem and motive for this research is described in this paragraph. The client who initiated the research has described that for the processes that project INDU-ZERO wants to make a blueprint for, specifically regarding logistics to the construction site and construction site assembly, the costs need to be reduced drastically and the processes need to be more efficient. This will be explained in the text below. All the different processes of the INDU-ZERO process are shown in Appendix 3: 'Full process of INDU-ZERO'.

1.2.1 Current processes and definition of scenario analysis and requirements

As described in sub-paragraph 1.1.3, INDU-ZERO is a project that develops a blueprint for a factory. During the project, work has been done regarding the development of the logistics, the products, the production, the factory layout and the construction site assembly (INDU-ZERO, sd). Currently, all processes of INDU-ZERO and specifics are being developed by a team of specialists. There are different products which different parties will deliver to build the INDU-ZERO blueprint and establish the processes for

INDU-ZERO. The reason for this is that other parts of the blueprint (for example the processes production and marketing) are covered in different studies by researchers of INDU-ZERO. Different scenarios are possible in terms of options (scenarios) for the renovation process (outbound logistics and construction site assembly).

1.2.2 INDU-ZERO's 50% goal & budget

The need for energetic renovation creates an enormous task with regard to the renovation of existing homes for housing corporations and residents of homes. This demand comes partly from the targets for CO2 reduction that must be met in Europe. Besides this, huge innovation potential is possible regarding industrialization and standardization as stated in sub-paragraph 1.1.2. Energetic renovations are already taking place, in order to achieve a substantial reduction in energy consumption, although it is happening at a very slow pace. In terms of technology and options, the goal is possible, but the costs of such a renovation are currently very high. The renovations that are happening at the moment are being carried out on a limited scale (Northsearegion, sd). This is mostly due to the costs of renovation which must drastically decrease. The goal of the project is to reduce the costs by 50%. This goal was established in a brainstorming session at the start of the INDU-ZERO project to promote creativity and achieve radical innovations.

The costs regarding construction site assembly and logistics to the construction site must be reduced drastically in comparison to the estimated costs of existing methods (Northsearegion, sd). According to a budget documented by the contractor Reinbouw, the costs of renovating a building is €97.578 on average at the moment. This amount is the total costs of the project and includes construction site assembly and outbound logistics but also other processes such as the production and purchasing the materials. This would mean that the budget for INDU-ZERO is €48.789. However, in this budget from a construction company, other costs are also included like production costs that will take place in the factory. The production & material costs have been calculated in previous research of a student of Saxion and is estimated at €34.831 (Efkemann, 2021) at the moment with €9.490 accounted for other costs such as sales, marketing etc. The transport costs are estimated at €360 at the moment (INDU-ZERO, sd). This will mean that a budget for construction site assembly of €4.108 can be established.

Items	Budget	Details
Production & materials	€ 34.831	Previous research
Transport	€ 360	Previous research
Other processes budget	€ 9.490	Current budget
Construction assembly	€ 4.108	Rest of the budget
Total	**€ 48.789**	**50% of the budget**

Table 1.1 (Conceptual) Budget INDU-ZERO

1.2.3 Calculations for the costs by previous research

A calculation had been made where the expertise and experiences from various experts was used to calculate the estimated costs for an INDU-ZERO package in terms of a target to focus on. In figure 1.2, the initial price calculation of the INDU-ZERO package is illustrated. The targets for construction site assembly (mounting) are currently €4000 and €360 for transport. The total cost price of a renovation package is

estimated at a target of €40.000 (Jansen, Darrouj, de Vries, & Ros, 2020). This is a broad estimation. In a follow-up calculation by an INDU-ZERO partner, the mounting (construction assembly process) was estimated at €8012 (INDU-ZERO, sd).

Percentage	Costs	Category	Description
1,00%	€ 570,00	Engineering	Measure software, configuration, data processing
50,00%	€ 20.000,00	Materials	Panels, roofs, installations
10,00%	€ 4.000,00	Production	Energy, workforce, inbound logistics, assembly, inbound/outbound production planning, quality control & traceability
1,00%	€ 360	Outbound logistics	Transportation per truck
10,00%	€ 4.000,00	Mounting	Disassembly, tenant guidance, assembly
3,00%	€ 1.000,00	Selling costs	Pre-sales and marketing, after sales, input from engineering, digital configurator
10,00%	€ 4.000,00	Fixed costs	Maintenance, management, proces engineering, product development, insurance
10,00%	€ 3.879,00	Capital costs	Depreciation, overhead, capital cost
5,00%	€ 1.921,00	Margin	
100%	€ 40.000,00	**Total**	

Figure 1.2 Old estimated cost targets for an INDU-ZERO package (Jansen, Darrouj, de Vries, & Ros, 2020).

1.2.4 Problem definition

The speed of renovation to energy neutral buildings needs to be increased to at least 50.000 houses per year (Rijksoverheid, sd). In terms of technology and options, the goal is possible, but the costs of such a renovation are currently very high. At the moment, the most important factor is the costs that need to be reduced by 50% which is the goal for the INDU-ZERO project. It is an ambitious goal from a brainstorm session like described before. Regarding the new process of logistics and construction site assembly the details, such as requirements, activities of the process and the cost price are not available yet. There is a particular need of a design of the process from outbound logistics till construction site assembly. A proper assessment of costs, requirements and choices is not available yet. With a proper assessment for the different renovation standards in terms of initial investment, activities, resources, number of employees, what equipment (for example using a crane, forklift, truck), strategy and the possibility of outsourcing is meant. This assessment and decisions are of uttermost importance to reduce cost and increase the speed of these processes.

1.2.5 Research scope

In the scope a description is given about what components are included in the research. The components included in the research are:

- This research specifically focuses on the costs and a plan for the logistics to the construction site and construction site assembly processes (can be summarized in the words “renovation process”).
- Multiple scenarios are necessary as input and are evaluated. The results serve as the strategy and methods to save costs. The most optimal and realistic scenario needs to be chosen and the costs calculated.
- The following aspects of the renovation process are based on results of previous research from INDU-ZERO partners:
    - Construction assembly: tasks and time needed for renovations and a crane planning from students at Saxion university.
    - Outbound logistics: calculation model of costs for in-house transport from a student at Jade University.
- The research was based upon previously identified technically specified activities regarding construction site assembly and transport.
- The research needs to conclude in an advice to make a choice between the scenarios as well as an implementation plan for the best fitting scenario;

1.3 Research objective

"Commissioned by the Sustainable Building Technologies (SBT) research group within Saxion University of Applied Sciences, to create the design of a process regarding logistics to the construction site and construction site assembly and to map the associated cost and create a strategy to reduce it by 50% in comparison to the current costs. Different scenarios are evaluated, after which advice is drawn up for implementation. The design and cost calculation will be handed over to Mr. Bazen before October 25, 2021. The ultimate goal is that a factory with construction site assembly and logistics to the construction site processes for delivering renovation packages is built."

1.3.1 Research question

"How can the process for the INDU-ZERO renovation packages be designed in terms of construction site assembly, outbound logistics so that a cost reduction of 50% is reached?"

1.3.2 DMADV (research framework)

The chapters of the research were divided based on the six-sigma framework DMADV. This can be put to good use in innovation projects to give a clear structure to the research, keeping the needs of the customer in mind at every stage (Selvi & Majumdar, 2014). The framework is essential in this research because a product is developed, a design of a process for which a clear structure is needed, and the needs of the customer are very important. The DMADV model is used to divide the research into phases. It concerns the following 5 phases. **Define**: In the define phase important needs and requirements are determined. **Measure**: This is where defined statistics and data are collected. **Analysis:** The result is analysed. **Design:** The results are compared with the needs and requirements. Adjustments are made. A detailed design is made. **Verify:** The product or service is released. In the verify phase, the design is compared with the needs and requirements (Selvi & Majumdar, 2014).

1.3.3 Sub questions

The following sub questions have been established in accordance with the research model DMADV:

Define

1. What are the current outbound logistics & construction site assembly processes for renovating houses?

Measure

2. What are the highest cost items for construction companies?
3. Where does the savings potential lie within the labour and material costs?
4. What decisions need to be made to establish the INDU-ZERO process?

Analyze

5. Which cost saving methods can be used within INDU-ZERO?

Design

6. What is the new INDU-ZERO planning and cost model?
7. How can the cost saving methods be implemented at INDU-ZERO?

Verify

8. How will the cost estimation and planning compare to the actual costs?

Chapter 2: Research design

In chapter 2, similar researches are described and theories that were used during the research. These theories were mainly used to accomplish the final results.

2.1 Similar researches

Several researches have been established on improving processes by data-based scenario analysis by other researchers on the internet. Researches on designing new processes have also been done. Besides this, previous studies and work has been done in general on developing an INDU-ZERO blueprint, including on subjects like the market, the costs and strategy of the project and other parts of the INDU-ZERO process such as production and marketing which processes are not included in this research. The most similar research is a research by 3 students at Saxion which claims that the renovation of one house can be done in 64 hours and cites the costs of €40.000 (Mensink, Beukering, & Hesselink, 2020). These are the costs of all processes of INDU-ZERO not just outbound logistics and construction site assembly (renovation process) The research which claim these costs was described in sub-paragraph 1.2.3.

In a research from the university of California which features implementing Lean construction, the applicability of Lean principles is to the construction domain is investigated and explored. In the research multiple factors are researched and the input and effect on the process. Controllable and uncontrollable factors were established, and different scenarios resulted in different cycle times (Abdulsalam, Diekmann, Songer, & Brown, 1999). In this research, multiple factors will also be established, and it will be checked if these factors are implementable for INDU-ZERO or not and checked for if they can be controlled. The most important result will be cost reduction however and the focus is less on the cycle time of the process, but this will also be an important result. In another research from the university of California, identifying and quantifying waste, development of Lean operations and improvement verification is described (Lee, Diekmann, Songer, & Brown, 1999). In a research from the university of Alexandria, the principles, methods, and implementation phases of Lean construction showing the waste in construction and how it could be minimized are described (Aziz & Sherif Mohamed, 2013). In this research, value will also be weighed against costs, waste will need to be identified in the current outbound logistics and construction assembly process. (Can be summarized in “renovation process”) from the construction company and this will need to be quantified into costs in order to map cost saving methods to reduce the renovation process costs by 50%.

In a research by Maria Cieśla, a practical approach to logistics strategies in enterprises and advanced practical applications is described. It presents an analysis based on make-or-buy decisions involving the selection of the best internal or external transport service. It presents the basis for a logistics strategy (Cieśla, 2015). This last research is related to the outsourcing part of establishing a process. These researches are examples of what the design of a more efficient new process could look like when implementing for example Lean principles and using measurables factors to do so (like

time or costs). Like the research on make-or-buy decisions, decisions for INDU-ZERO will need to be made with a practical approach in order to come to results. This is because at the end of the INDU-ZERO project the decisions will need to be made and a rational and practical approach based on costs will be the best probable way to come to the most optimal decisions to establish the most optimal renovation process.

2.2 Theories & research framework

The theories and research framework used in this research are described below. Throughout the research, these theories have been used to eventually accomplish results. The theories were based on the strategy of industrialisation in the construction industry and standardizing it like described in chapter 1 and saving costs and time with certain solutions such as a planning which will be discussed later in this research.

2.2.1 Standardizing and reducing waste (Lean construction)

The INDU-ZERO factory that is being developed can produce renovation packages. As described in chapter 1, the process is presumably more standardized than regular construction because products for houses are produced instead of regular construction. Because of this transformation, Lean construction seems to be the next logical step for innovating the construction industry. Lean production was developed by Toyota led by Engineer Ohno. The term “Lean” was coined by the research team working on international auto production to reflect both the waste reduction nature of the Toyota production system and to contrast it with craft and mass forms of production. Lean construction accepts the Ohno’s production system design criteria as a standard of perfection. The construction industry has rejected many ideas from manufacturing because of the belief that construction is different. Manufacturers make parts that go into projects but the design and construction of unique and complex projects in highly uncertain environments under great time and schedule pressure is fundamentally different from making tin cans (Howell, 1999). The first issue with implementing Lean would be that you can’t implement these principles since the construction process and bringing the goods to the site aren’t production processes. This is not completely true. It can be argued that the construction process has been more of a service process in the past, but it’s not true that the construction process can’t in fact be a production process with the necessary changes. The way INDU-ZERO sees it is that a house that is renovated is a product of INDU-ZERO. The process is standardized as much as possible, and the construction process must merely be assembling the house like a product in a factory. This is why INDU-ZERO’s process can be no different from producing in a factory. For this reason, Lean is a perfect solution for INDU-ZERO to improve its process and accomplishing its goals for price, speed and value. The Lean strategy of reducing waste was used for removing tasks and resources that aren’t necessary in the renovation process and for making the process as standardized as possible based on Lean construction.

2.2.2 Strategy: Quick response manufacturing (QRM)

In chapter 1, industrialisation of construction was described and standardization which is happening more and more. This is why quick response manufacturing, or a process based on quick response manufacturing is currently the best approach for

INDU-ZERO's processes of logistics and construction assembly. Both methodologies QRM and Lean have only one goal in mind: to reduce lead time (Veltion, 2016). QRM is a strategy for reducing lead-times across all functions of an organisation. The resulting improvements in speed and responsiveness increase the organisation's agility and responsiveness, resulting in competitive advantage. Many well-known Lean Manufacturing tools have been developed for high volume/low variety, or 'mass production' environments. QRM is basically a modified form of Lean (Procesverbeteren, sd).

2.2.3 Planning: (Lean techniques & QRM) Cellular manufacturing, one-piece-flow (for an INDU-ZERO planning)

Now that a strategy has been established In Lean manufacturing, techniques can be found to create a cell that consists of a close arrangement of the people, machines, or workstations in a processing sequence. You create cells to facilitate one-piece flow of a product or service, through various operations, for example, welding, assembly, packing, one unit at a time, at a rate determined by the needs of the customer and with the least amount of delay and waiting (Liker, 2004). "One piece flow" (also known as "single piece flow" or "continuous flow") defines a manufacturing process in which all of the work on a single product is completed before moving onto the next unit (Mazanec, 2016). Making huge gains in productivity and quality and big reductions in inventory, space, and lead time through one-piece-flow has been demonstrated over and over in companies throughout the world. This is why the one-piece-flow cell is the "ultimate" in Lean production (Liker, 2004). In QRM Cellular manufacturing it is also used, but more designed around a segment of the market in which shorter product lead times provide the company with maximum benefits (Suri, 2010).

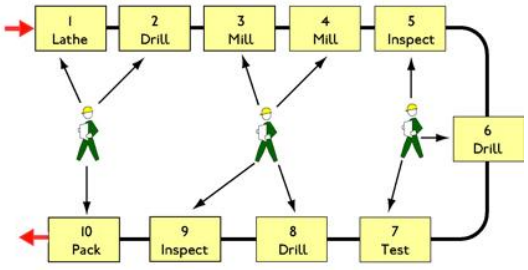

Figure 2.1 Manufacturing with a cellular system

2.2.4 Planning: Variability & reducing disruption in the planning (QRM)

Planning to 80% of the maximum capacity is a subject from the concept 'System Dynamics'. With QRM it's all about time and striving to minimize waiting time in the entire system. In order to achieve this, it's important to realize the largest possible flow. By flow we mean that the orders flow quickly through the organization, with hardly any delay (qrminstitute, sd). In figure 2.2 below two curves are shown. The top curve shows a scenario in which a manufacturing system has a high amount of variability, and the lower curve shows a system with a lower amount of variability. In this case the system is the process of construction site assembly with additionally the outbound logistics. It can be used for INDU-ZERO for a less variable planning. With variability any kind of delay or disruption to the system is meant. This could mean:

- Absenteeism.

- Machine breakdown.
- Quality problems;
- Customer requests for changes to the product (UW-Madison engineering professional development, 2020).

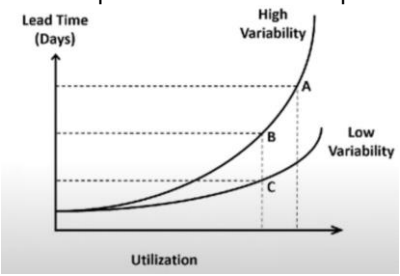

Figure 2.2 Variability in processes (UW-Madison engineering professional development, 2020)

2.2.5 Planning: Creating a one-piece flow (QRM)

For an optimal process, we want a smooth flow. Creating one-piece flow for a smooth flow is done as gradually as possible, making only what is needed for the next step. Basically it's about a continuous flow, becoming a sequel of classic batch-and-queue all at once with materials waiting to go in the process (One-piece-flow, sd). An example in construction is for example if 1 day per house is spent on each building layer (floor, shell, roof), (or "vloer, casco, dak" in dutch). In figure 2.3 below it is shown in the left picture (batch production) that the first house is not ready until day 31. In the picture on the right, the house is ready on day 4. But when building in batches, people deliver everything at once, which is only possible – in this example – on day 40. With one-piece flow, all 10 houses can already be delivered after 13 days. (Although this is of course also delivered individually, so from day 4 a house is delivered every day). Examples of advantages of one-piece-flow are:

- By building flow into your process, you ensure that waste becomes (intermediate) stock, growth and transport.
- Since each product of service remains in process through completion, the lead time is shortened, and you have to deal with minimal inventory;
- In addition, you ensure that you build quality into your process. If it is done individually or in small batches, you can correct errors more quickly and you don't have to get rid of huge amounts of correction (Bureau Tromp, sd).

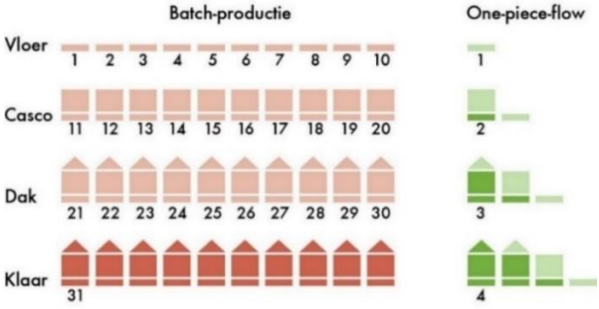

Figure 2.3 Example of one-piece flow in construction

2.3 Research type

The research mainly concerns a desk research and design-oriented research. It is mostly a quantitative research, because mostly numerical data was collected and analysed. This data includes financial data and time in hours. Numerical data was the

focus because a goal of 50% reduction of the costs must be accomplished. In desk research, the questions or problems are answered and investigated using existing information and data that was already collected by others. Design-oriented research is one of the types of research that investigates questions and problems from practice. It focuses on improving the current practice or the development of a new practice. The final product was developed by using a methodical design process.

2.4 Reliability and validity

The reliability of the research means that the results of the research are the same if the research is carried out again in exactly the same way. Validity is about how accurately a method measures what it is intended to measure (Scribbr, 2016). By using methods and information used by the stakeholders and communicating the steps the reliability of the research will improve. The research was mainly based on facts and arguments to back up claims and numbers. In every step, stakeholders such as contractors, housing corporations and project partners were contacted, and feedback was given. After brainstorming and interviews and other data collection steps, data was checked with the client and project partners such as experts on the construction process to verify if the data was accurate and needed. Existing material and sources were checked for facts. In addition to all this, in the last phase of the research, an evaluation was made to make sure results are verified by comparing data and collecting information from multiple stakeholders who have affinity with these kinds of projects and have done relatable projects. To verify the time needed to renovate a house regarding the planning, experts have been contacted. The end results were shown to experts and the main outcomes have been compared to actual examples which are used in construction companies. Data on costs and scheduling has been confirmed by various experts who have knowledge of construction engineering.

2.5 Research design

In Table 2.4, the research design is illustrated. The details are explained further in sub-paragraphs 2.5.1 and 2.5.2.

Phase	Research questions	Data collection	Data analysis	Results
Define	1. What are the current outbound logistics & construction site assembly processes for renovating houses?	Collecting existing data: planning from construction company, previous INDU-ZERO research	Work Breakdown Structure Diagram	Current processes
Measure	2. What are the highest cost items for construction companies?	Collecting existing data: budget from construction company	Pareto analysis	Highest cost items
Measure	3. Where does the savings potential lie within the labour and material costs?	Literature review: articles on savings potential, collecting existing data: interviews, meetings and personal communication	What-if scenario analysis	Categories in which savings potential lies

Measure	4. What decisions need to be made to establish the INDU-ZERO process?	Literature review: theory on decisions to be made by van Amstel, collecting existing data: interviews, meetings and personal communication	What-if scenario analysis	Potential decisions to be made
Analyze	5. Which cost saving methods can be used within INDU-ZERO?	Collecting existing data: multiple sources for cost estimations. Interviews, a brainstorm session and personal communication	What-if scenario analysis & decision tree	Cost saving methods and solutions
Design	6. What is the new INDU-ZERO planning and cost model?	Existing data: multiple sources for costs. Interviews, two brainstorm sessions, meetings, and personal communcication	Cellular manufacturing, Critical path method, using system dynamics	Schedule and project planning
Design	7. How can the cost saving methods be implemented at INDU-ZERO?	Existing data: Multiple sources for costs such as a budget from two construction companies.	Calculation model, planning and what-if scenario analysis	Cost model, best practice
Verify	8. How will the cost estimation and planning compare to the actual costs?	Existing data: data from other projects. Meetings, personal communication.	Triangulation	Verified solutions and best practice

Table 2.4 Research design

2.5.1 Data collection & justification of sources

As written in the introduction, this study is part of the INDU-ZERO project and builds strongly on previous work done within this larger project. However, since the project is not finished yet (expected end date of the project is May 2022), most of the results of previously completed project work has not been officially published yet. Project results, worked on by different researchers at Saxion and other project partners, are shared internally among each other by means of an internal shared platform (OneDrive). Therefore, results of previous parts of the project cannot be referred to in a normal way, with standard APA referencing. Instead, the author of this study has chosen to refer to these sources with mentioning for example “a researcher from Saxion”. The exact source is in all cases known by the author of this study, and in case it is desired, he can provide further details and/or contact the relevant researcher at Saxion, to provide all requested additional information.

For the data collection, in the define phase, data was mainly collected by using existing data to define the current process for a construction company and the conceptual process of INDU-ZERO. A planning and budget from a construction company and

previous INDU-ZERO research was used to establish both processes and tasks necessary to complete a renovation process for a house. The measure phase consisted of collecting data from a budget from a construction company in order to establish the highest cost items in the renovation process. To establish where the savings potential lies within the labour and material costs, data from two literature sources, 4 interviews, meetings and personal communication were used in order to establish potential ways to save costs and what decisions need to be made to establish the INDU-ZERO process. In the analyze phase, multiple sources for cost estimations (Appendix 15: 'Estimated costs and savings of cost saving methods & decisions'), interviews, a brainstorm session and personal communication was used to collect information on implementable methods to save costs. In the design phase, multiple sources to establish the costs were consulted (Appendix 18: 'Cost model') such as the budget from two construction companies. Interviews, two brainstorm sessions, meetings were held to collect data for the planning. The planning and cost model itself were used in order to see how the methods could be implemented in the INDU-ZERO process. In the verify phase, data from previous research, meetings and personal communication was used in order to compare the results (costs and the planning) to previous renovation projects. Meetings and personal communication were also used to do this. The collection methods are used because it is a useful and realistic approach of collecting data for this type of research. Regarding the interviews, they were held with a concept developer for a contractor in construction, 2 researchers at Saxion and a researcher from another university (Appendix 9: 'Interview 1', Appendix 10: 'Interview 2', Appendix 11: 'Interview 3' and Appendix 12: 'Interview 4'). In Appendix 5: Correspondence: brainstorm sessions, meetings & personal communication the correspondence that has taken place is described.

2.5.2 Analyzing the data and results

In terms of methods to analyse the data, various models and theories were used, shown in table 2.4. In the define phase, a Work Breakdown Structure Diagram (WBS) was used in order to categorize INDU-ZERO's tasks into sub-processes to compare them to the construction company steps to renovate a house, to see which sub-processes or tasks can be scrapped and to map the amount of work necessary and time needed for each sub-process. In the measure phase, the costs from the construction company were divided into cost items by the researcher and the construction site assembly team from INDU-ZERO to find the categories for cost items with the highest costs. To analyze all the cost saving methods and decisions to be made for a new INDU-ZERO process, multiple what-if scenario analyzes were made in the measure and analyze phase. In the design phase, a cellular manufacturing, the critical path method and using system dynamics were used to standardize the planning and reduce waste. The internet tool Miro, Microsoft Project and Microsoft Excel were used to create the solutions to establish the INDU-ZERO process including cost saving methods. In the verify phase, data from the conceptual INDU-ZERO process was compared with data from other renovation projects. The time the process takes was also confirmed with personal communication. The final result will be data solutions which are in this case a planning and cost model which conclude in financial and time savings.

Chapter 3: Current situation

In this chapter the 1st research question will be answered: "What are the current outbound logistics and construction site assembly processes for renovating houses?". The chapter corresponds to the Define phase of the research. To answer this question the current renovation process of INDU-ZERO partner Reinbouw and of INDU-ZERO itself (conceptual) were mapped for the renovation to energy efficient houses. The time and efficiency can be compared too when doing this and in the next chapters the costs of the INDU-ZERO process is calculated.

3.1 Data collection

As described, the process and costs need to be established. A business process is a collection of linked tasks for the delivery of a service or product to a client (Appian, sd). So first of all, the tasks to complete a renovation need to be established. The following sources were used to establish tasks and time needed to complete the tasks:

- **INDU-ZERO tasks and time**; A previous research by students from Saxion university, which has based the data on interviews with contractors who specialize in construction site assembly activities, has shown that it takes about 135 hours to carry out all activities to renovate a terraced house. By moving some operations to the factory and not doing unnecessary activities, it can be done in 64 hours (Mensink, Beukering, & Hesselink, 2020). Based on another previous research, there are a total of 59 tasks that need to be completed to complete these processes. These tasks are done in 3 different phases with 11 different sub-phases. The tasks were mapped in a previous research by a researcher construction engineering at Saxion University. In Appendix 4: 'INDU-ZERO tasks and time' the result of this research is shown. The number of hours was later adjusted to 92 netto hours (employees times hours) after adjustment by a student construction engineering and meetings with the INDU-ZERO team. Appendix 5: 'Correspondence: brainstorm sessions, meetings & personal communication' states what was discussed in these meetings. However, when more than 1 employee are working simultaneously, the tasks will take about 52,25 hours in terms of hours needed for the renovation with a variable number of employees.
- **Construction company process steps and time**; A planning from the construction company Reinbouw. This data was collected from a project planning of Reinbouw by personal communication with a concept developer at Reinbouw. The planning consists of 21 tasks and 17 days to complete a renovation (including day 0). The renovation process of construction companies takes place mainly on the construction site and there are a lot of variable tasks that are done in different orders. However, the steps that need to be taken to renovate a house is illustrated in the planning. Reinbouw is the most optimal source of information currently on what the process of renovation currently looks like because the process very similar to the INDU-ZERO process like described in sub-paragraph 3.2.1. The planning is shown in Appendix 6: 'Planning renovating houses by construction company'.

3.2 Analysis of the renovation process

In order to establish the current process of construction site assembly and outbound logistics, first the renovation process of a house to energy neutral was mapped and all the products that this process delivers. After this, a WBS was used to determine INDU-ZERO's sub-processes so that the tasks can be compared to the steps the construction company takes in its planning to renovate a house. These conceptual INDU-ZERO sub-processes were then assigned to the corresponding sub-processes of the construction company. The time needed for each process was added up for INDU-ZERO and compared to the time needed for the construction company.

3.2.1 Renovation of a house to energy neutral (Reinbouw & INDU-ZERO)

The construction assembly process takes place on the construction site, which in case of renovations are private homes or can be social housing. The contractor ensures optimal airtightness from the inside, insulation of floors, the roof and the cavity wall and installs triple glazing. They install solar panels which generate energy. A plug & play energy module with a heat pump, a heat recovery ventilation system, an invertor and boiler is placed on the roof. For existing walls, heat is released via low-temperature wall heating. By monitoring and metering, data can be checked to check if the proposed goals are achieved (Reinbouw, sd). INDU-ZERO renovation packages consist of insulation material for walls and roofs, heat pumps, solar panels, energy converters and ventilation systems. Most of these products are set to be made in a factory. The main difference is that INDU-ZERO aims to produce and apply these packages half of the current price. Another difference is that INDU-ZERO has a standardized approach and focusses on terraced houses and apartments built between 1950 and 1985 (Northsearegion, 2021). The products of a renovation package are shown in figure 3.1.

Figure 3.1 Renovation to an energy neutral house

3.2.2 Business model: Work breakdown structure (WBS) (sub-processes)

The tasks necessary to renovate a house for INDU-ZERO are known. In order to compare the tasks to a construction company and to conclude how much work is done the tasks need to be categorized in a certain sub-process. To start a project (like renovating a house), a decomposition of work to be executed is necessary (Workbreakdownstructure, sd). A WBS is possible, which is a deliverable-oriented hierarchical decomposition of the work to be executed by the project team to

accomplish the project objectives and create the required deliverables (Visual paradigm, sd). A phase-based WBS, in which elements are the unique deliverables in each phase, was the most helpful tool in this case because the INDU-ZERO process phases have not been established yet and deliverables have. The diagram was essential to determine sub-processes. After sub-processes of INDU-ZERO were established, the process could be compared to the construction company's process and a process structure was established. The diagram was essential to determine which tools and resources are required which is essential for creating the process and determining the costs.

3.2.3 Designing INDU-ZERO's sub-processes using a WBS & excluding tasks

The WBS based on INDU-ZERO and a construction company's process of renovating houses is shown in Appendix 7: 'Work breakdown structure & assigning tasks to the WBS phases'. It was made by the researcher based on the tasks from Appendix 4: 'INDU-ZERO tasks and time'. In Appendix 7: 'Work breakdown structure & assigning tasks to the WBS phases' the tasks from Appendix 4: 'INDU-ZERO tasks and time' have been sorted into a sub-process and given a name and number. The INDU-ZERO tasks are shown on the in the figure and the new name and number for the sub-process which the tasks have been categorized in by the researcher under "WBS phase". The budget and work needed to complete the tasks has also been distributed equally to all the phases based on the time needed per task. The work percentage is based on the task time. The phases are: preparation of the building site, preparation of terrain, adjust sewage system, precaution for mounting elements, remove roof elements, preparation of the building, new façade, new roof, solar panels, installations, finishing the house and cleaning up the building site.

3.2.4 Construction company vs INDU-ZERO

Based on the current data, an overview was made of the current process for the construction company compared to INDU-ZERO's conceptual process. An example is that for example the task "new roof" of the construction company is the same as INDU-ZERO's tasks add roof elements, fixate roof elements and other roof related elements which were categorized together in the last sub-paragraph. The overview is illustrated in figure 3.2. In the figure, the construction company's process is illustrated on the left with next to it on what date the work is executed. These are multiple tasks which will result in completion of the sub-process (one step). For example, multiple tasks will be done to eventually complete the first sub-process which is cleaning up the bedroom/attic. In the figure, the corresponding sub-processes of INDU-ZERO have been assigned construction company's sub-processes to compare both processes. Some process steps have been left out. This will be further explained in sub-paragraph 3.2.5. The reason these process steps are not included is because these items are exclusive tasks and will not be featured in the main INDU-ZERO process according to the researchers at Saxion. The tasks are examples of house and customer specific tasks that can be scrapped to reduce time. The sub-processes that aren't part of INDU-ZERO's main tasks according to the INDU-ZERO construction site assembly team have been marked with a cross.

Day (construction company)	Construction company	INDU-ZERO	Description
Day 0	Cleaning up bedroom/attic (asbestos)		Task for removing asbestos. Removing asbestos is an optional task that INDU-ZERO won't include in its main process
Day 1	Covering floors and stairs		Covering floor and sand to reduce cleaning tasks. Less activities are done inside and the conclusion was made to not include this task.
Day 2	Removing asbestos		Task for removing asbestos. Removing asbestos is an optional task that INDU-ZERO won't include in its main process
Day 3	Remove paving/garden	1.2 Preparation of terrain	The terrain will be prepared for the renovation. Tasks such as removing vegatation, garden fences and creating an excavation trench around the house. According to Appendix 4: INDU-ZERO tasks and time INDU-ZERO can do this in 2,75 hours with 2 employees.
Day 4	Adjust sewerage/ rainwater drainage	1.3 Adjust sewage system	The sewage system will be adjusted. This includes tasks such as removing pipes and rainwater drainage systems. INDU-ZERO can do this in 2 hours with 2 employees.
Day 5	Preparations façade	2.1 Preparation of the building	Preparation of the building to place the façade and also for a few installations and roof. This includes tasks such as disconnecting energy components and disconnecting outside components such as a doorbell and lightning. INDU-ZERO can do this in 2,75 hours with 1 employee.
Day 6	Place scaffolding	1.4 Precaution measurements for mounting elements	Placing the triangle scaffold which is a new type of scaffold which will be later analysed in chapter 4. INDU-ZERO can do this in 1 hour with 2 employees (with the use of a crane).
Day 7	Removing gutters/roof tiles	1.5 Remove roof & façade elements	Removing all components from the roof to replace old roof with the new roof. Includes tasks such as removing rooftiles and removing the chimney. INDU-ZERO can do this whole sub-process in 8 hours with 2 employees.
Day 8	Removing façade (window frames)	1.5 Remove roof & façade elements	Removing the elements in order to place a new façade. This includes tasks such as removing glass from the window frames and mullions. INDU-ZERO can do this whole sub-process in 8 hours with 2 employees.
Day 8	New façade	2.2 New façade	Placing the new façade with a crane and fixating it. Fixating the façade will be done with a new type of anchor which will be discussed in chapter 4. INDU-ZERO can do this in 3 hours with 3 employees
Day 9	New roof	2.3 New roof	Placing the new roof and fixating it using the crane (among other tools). INDU-ZERO can do the whole sub-process of placing a new roof in 5,5 hours with a maximum of 3 employees.
Day 10	Roof tiles	2.3 New roof	Placing the new roof and fixating it using the crane (among other tools). INDU-ZERO can do the whole sub-process of placing a new roof in 5,5 hours with a maximum of 3 employees.
Day 11	Solar panels	2.4 Solar panels	Connecting the solar panels. INDU-ZERO can connect the solar panels in 0,5 hours with 1 employee.
Day 11	Ground floor insulation		Applying isolation for the floor. Not included in the main tasks. This is because in many homes it is already at a comfort level design.
Day 11	Checking activities/cleaning up	3.2 Finishing the house	Finishing activities. For INDU-ZERO, this means finishing the inside and outside of the house. It includes tasks such as finishing a window frame and leveling the garden. INDU-ZERO can do the whole sub-process in 8,5 hours with a maximum of 2 employees.
Day 12	Dismantle scaffolding	3.3 Cleaning up the building site	Cleaning up the building site and removing equipment. INDU-ZERO can do the whole sub-process of cleaning up the building site in 2,25 hours with a maximum of 2 employees.
Day 12	Indoor installations	3.1 Installations	Placing and adjusting the installations in the house. This includes tasks such as placing a SKID and adjusting the fusebox. INDU-ZERO can do the whole sub-process of installations in 14,5 hours with a maximum of 2 employees.
Day 13	Balancing/checking installations	3.1 Installations	Placing and adjusting the installations in the house. This includes tasks such as placing a SKID and adjusting the fusebox. INDU-ZERO can do the whole sub-process of installations in 14,5 hours with a maximum of 2 employees.
Day 14	Supplementing/repairing groundwork	3.2 Finishing the house	Finishing activities. For INDU-ZERO, this means finishing the inside and outside of the house. It includes tasks such as finishing a window frame and leveling the garden. INDU-ZERO can do the whole sub-process in 8,5 hours with a maximum of 2 employees.
Day 15	Withdrawal building contractor		No time nescessary for this activity in the main tasks.
Day 16	Cleaning up	3.3 Cleaning up the building site	INDU-ZERO can do the whole sub-process of cleaning up the building site in 2,25 hours with a maximum of 2 employees.
		1.1 Preparation of the building site	This is an extra sub-process which needs to be done for INDU-ZERO. It includes placing containers, delivering the materials and making everything ready. The construction company does these tasks but doesn't have a sub-process or clear tasks for this. INDU-ZERO can do this in 1,5 hours with 1 employee.

Figure 3.2 Construction companies process vs INDU-ZERO incl. time & employees needed (incl. input from 3.2.5)

3.2.5 Removing tasks based on INDU-ZERO's strategy

As seen in figure 3.2, next to some of the sub-processes that the construction company does, a cross is shown on the INDU-ZERO process. INDU-ZERO will leave out these sub-processes from its total process. The reasons for this are described in the figure and sub-paragraph 3.2.4. The sub-processes are:

- **Day 0: Cleaning up bedroom/attic (asbestos).**
- **Day 1: Covering floors and stairs.**
- **Day 2: Removing asbestos.**
- **Day 11: Ground floor isolation.**
- **Day 15: Withdrawal building contractor.**

3.2.6 INDU-ZERO's conceptual process: Total hours, days and employees

An indication of the time and employees needed for INDU-ZERO given in the description in figure 3.2. In total, the whole conceptual process will last 52,25 hours and a variable number of employees is necessary for each sub-process with a maximum of 3 employees. This results in a total of 7 days for the full renovation of 1 house. This is a difference of 10 days less time it takes for INDU-ZERO to renovate a house for the conceptual process.

3.3 Results

The analysis of the construction company against INDU-ZERO's conceptual process resulted in a difference of 10 days. A total of 5 sub-processes were included in the construction company's process but not in INDU-ZERO's process. 1 Sub-process of INDU-ZERO wasn't included in the construction company's process. A reason for why these tasks weren't included was described in sub-paragraph 3.2.5. Besides the exclusion of these tasks, the conceptual process of INDU-ZERO still requires less time. When subtracting the non-essential construction company tasks with INDU-ZERO's total time the INDU-ZERO process still requires 5 days (12 days construction company non-essential tasks minus 7 days for INDU-ZERO's conceptual process) less to complete. The full process of both the construction company and INDU-ZERO is shown in figure 3.2.

3.4 Conclusion

In chapter 3, the current INDU-ZERO renovation process has been mapped and analysed. The conceptual process is similar to the construction company's process but can be completed in a shorter amount of time (10 days shorter), excludes some tasks and is presumably more efficient. INDU-ZERO's tasks haven't been sequenced and no clear strategy or reason for the time difference and potential cost difference exists in the current process yet. This information will be established in the next chapters. These results are shown in table 3.5 below.

Item (when renovating 1 house)	Details
Construction company's renovation	17 days (including day 0)
Construction company's renovation	16 days (excluding day 0)
Estimated labour costs	€18.360
INDU-ZERO's renovation (conceptual)	7 days (no sequencing tasks & methods)
Difference	10 days

Table 3.5 Conclusion

Chapter 4: Savings potential & decisions to establish the process

In this chapter the 2nd, 3rd and 4th research questions: "What are the highest cost items for construction companies?", "Where does the savings potential lie within the labour and material costs?" and "What decisions need to be made to establish the INDU-ZERO process?" will be answered. It corresponds to the Measure phase of this research. To answer these questions first the highest cost items were established. After this the methods that can possibly result in saving costs and decisions were established. The methods and decisions were analysed in this chapter by using theories found by the researcher and cost saving possibilities. However, as described, the process of renovation for INDU-ZERO is also not established yet. This means the decisions and savings methods and possible data solutions must result in a new process with new cost saving methods. This new process can later be compared to the old process of renovating houses. To establish a new process a lot of decisions need to be made. These decisions and solutions will be defined in this chapter.

4.1 Data collection

The data collection for this chapter to find the savings potential and decisions to establish a new process consists of:

- **Highest cost items construction company:** To find out what the highest cost items are, a budget has been collected from a concept developer at Reinbouw. Besides this, personal communication has taken place about the costs and this budget. Appendix 5: 'Correspondence: brainstorm sessions, meetings & personal communication' states the full list communication for the data collection of this research.
- **Articles on cost saving opportunities;** 6 articles from 3 companies, a financial and a human resources blog have been collected. These articles state potential ways of saving costs within labour and material costs. The research area was usable methods from companies or experts in the field of business administration, human resources and finance. The list includes 5 sources and 6 articles from 3 companies, a financial and a human resources blog. After further search for more articles, more than half of other techniques were the same or relatable techniques. Almost all new articles could be placed in the already established categories. Because of this, the researcher made the conclusion that the list in the researched area had been completed. In Appendix 8: 'Literature research: Articles for cost saving opportunities' the details of this literature research is described.
- **Interviews:** Four interviews on decision making & saving potential have been held with a concept developer, a researcher at Saxion and a student at Jade university. The interviews are illustrated in Appendix 9: 'Interview 1', Appendix 10: 'Interview 2', Appendix 11: 'Interview 3' and Appendix 12: 'Interview 4'.
- **Decisions necessary to establish a new process;** A theory from a book called 'Logistiek' by van Amstel which states decisions that need to be made to

establish a process. In Appendix 13: 'Literature research: Decisions necessary to establish a new process (according to van Amstel)' these decisions are described.

- **Potential ways of saving costs & time saving opportunities**; Besides the literature research, this information was collected from experts in meetings with the INDU-ZERO business and construction site assembly team. Appendix 5: 'Correspondence: brainstorm sessions, meetings & personal communication' states the full list of communication for the data collection of this research.

4.2 Analysis

After the savings potential and decisions to establish a new process have been found based on what the highest cost are in the renovation process, multiple scenarios can be found after analyzing the data. Scenario analysis is a strategic process of analyzing decisions by considering alternative possible outcomes. It is not a predictive mechanism, but rather an analytic tool to manage uncertainty today (Lumen, sd). Specifically, a What-if analysis is used to explore and compare various plan and schedule alternatives based on changing conditions (Safran, 2017). This is done by mapping every single possibility based on the literature research (Appendix 8 and 13), interviews and other communication collected by the researcher.

4.2.1 Highest cost items construction company renovation (Pareto)

The researcher has asked Reinbouw the budget of different costs for a renovation. The costs of the construction companies budget can be divided into a lot of cost items and material costs are also included. To find the costs for labour and tools, the costs of the budget have been divided into cost items by the researcher. In this cost division some cost items can be observed that aren't included in the INDU-ZERO process according to 2 researchers at Saxion (Personal communication, 2021, Salemink). These cost items are removing asbestos, renovating the kitchen, renovating the toilet and renovating the bathroom. The costs for labour have also been separated from materials by calculating the hours needed and using salary costs and separating this from materials. A concept developer at Reinbouw has confirmed that the labour cost component in construction is approximately 45% for all products. As seen, the costs consist mainly of labour and material costs (at least 82,7%). An overview of this division of the costs is illustrated in Appendix 14: 'Estimation costs Reinbouw' and figure 4.1 in a pareto analysis.

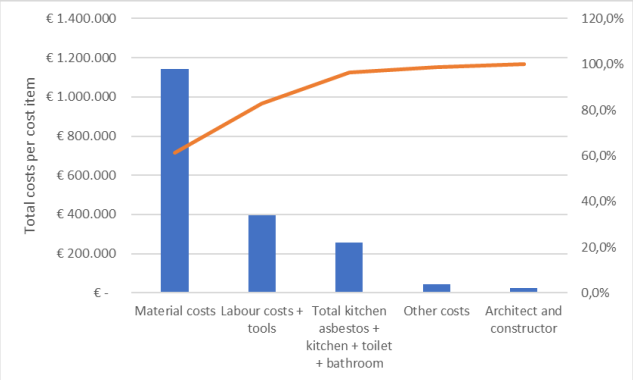

Figure 4.1 Costs for 26 houses divided into categories (from budget of Reinbouw)

4.2.2 Cost saving methods from interviews and communication

In chapter 2 and 3, it was concluded that besides the time savings of scrapping tasks and the reduced time the process itself, a lot of costs and time savings still need to be realised. First of all, the available information on time reduction and possible cost reduction within the INDU-ZERO construction assembly team is the following which are ideas to save time and costs (categorized by the researcher):

- **New resources vs old resources (New resources);** according to a researcher at Saxion, at least 30 hours can be saved which corresponds to about 2 days and an unknown amount of costs. However, more methods are included in the conceptual INDU-ZERO process which have not been proven to save time and it is not known if these methods can be implemented. These will be analyzed in chapter 5.
- **Training (Training);** according to an augmented reality specialist from Buro de Haan, a partner of INDU-ZERO, costs can potentially be saved by implementing a training tool.

In the interviews held, the following ways to save costs were established after coding the interviews (categorized by the researcher):

- **New resources vs old resources (New resources);** a scaffold and other resources such as a new anchor type to fixate walls can save costs which are types of equipment (resources) in the process used for the tasks. According to a researcher at Saxion and a concept developer at a construction company it can save time and costs (Appendix 9: 'Interview 1', Appendix 10: 'Interview 2').
- **Standardizing the construction process (New resources & planning);** standardizing the construction process can save a lot of costs was suggested by a researcher at Saxion in Appendix 12: 'Interview 4'.

4.2.3 Decisions to be made according to interviews and communication

For a new process to be established a lot of decisions need to be made. To do this, the theory for decisions that need to be made in processes and the interviews will be analysed which concludes into the most important decisions to establish the basic process of INDU-ZERO. Decision-making is regarded as the cognitive process resulting in the selection of a belief or a course of action among several possible alternative options (Simon, 1977). In the interviews and meetings held, the following decisions to establish the process were established after coding the interviews (categorized by the researcher):

- **How many employees**; (Planning)**;** how many employees are deployed for each task according to a concept developer at a construction company and a researcher at Saxion (Appendix 9: 'Interview 1', Appendix 10: 'Interview 2').
- **Planning** (Planning); a possible planning for resources can be made such as a planning for the crane according to a concept developer at a construction company and a researcher at Saxion (Appendix 10: 'Interview 2').
- **Outsourcing** (Outsourcing); according to the INDU-ZERO business team, decisions need to be made on outsourcing the processes construction site assembly and outbound logistics or not outsourcing them.

4.2.4 Setting up categories for scenarios

Managers and employees need to make a lot of decisions to accomplish optimal processes (van Amstel, 2021). According to an interview with the client, a what-if scenario analysis is necessary to establish cost saving methods and a new INDU-ZERO process. Theories were used as a basis for potential cost savings and potential decisions to establish processes in Appendix 8: 'Literature research: Articles for cost saving opportunities and Appendix 13: 'Literature research: Decisions necessary to establish a new process (according to van Amstel)'. Besides this, interviews and meetings were held and analysed, and the current process was analysed in sub-paragraphs 4.2.1 till 4.2.3. Throughout this whole chapter, all these potential cost saving methods and decisions were categorized. This was done in order to establish a list of subjects that need to be included in a scenario analysis. The subjects and sources are summarized and illustrated in table 4.2 below. No sources have mentioned the categories contracts. The fact that INDU-ZERO currently only has a conceptual process which has not been tested could explain this. According to the client, a document has to be signed by multiple parties after which the production and services will later be established. Contracts with suppliers and other parties are included in this. When this will be established will be discussed in the implementation plan in chapter 7.

Subjects	Theory source	Interview/communication sources (paragraph 4.1 & 4.2)
Training	Articles	Interview 1, 2, Personal communication
Planning	Logistiek by van Amstel, articles	Brainstorming, Interview 2
New resources	Logistiek by van Amstel, articles	Interview 1,2 and 4
Outsourcing	Logistiek by van Amstel, articles	Brainstorming with the INDU-ZERO team, Interview 3
Contracts	Articles	Not mentioned (plan for the future will be discussed in ch.7)

Table 4.2 Cost savings and decision categories for INDU-ZERO

4.2.5 Formats for data solutions

After the decisions that need to be made have been found, probable solutions need to be found to make the scenario analysis. It is clear that there is a lot of data necessary for the decision making for INDU-ZERO. For example, a lot of financial and time data is needed. This will mean decisions need to be based on actual data rather than intuition or observation alone. This is called data-driven decision making (Northeastern University, 2019). Date and time data types include the following: date, time, timestamp and interval (Actian, sd). Financial data consists of pieces or sets of information related to the financial health of a business (Study, 2021). The decisions in table 4.3 have been sorted to what type of data is necessary for a solution. After the data type was established, a format for a solution was found by using the data type and meetings with the client for the most optimal solution to establishing the INDU-ZERO process.

Decisions	Type of data	Format
New resources	Scheduling & financial	Planning & cost model
Planning	Scheduling & financial	Planning & cost model
Training	Financial	Cost model
Outsourcing	Financial	Cost model

Table 4.3 Solutions for future decisions

4.3 Results

A lot of information has been found on where savings potential lies for INDU-ZERO and what decisions need to be made to establish a new INDU-ZERO process. The information can be categorized into 4 subjects:

- New resources.
- Training.
- Planning.
- Outsourcing.

The results are illustrated below in figure 4.4. In the figure, the potential possibilities to save costs and decisions to establish a new process are shown on the left side with its different categories. The specific possibilities and decisions are shown in Appendix 8: 'Literature research: Articles for cost saving opportunities, and Appendix 13: 'Literature research: Decisions necessary to establish a new process (according to van Amstel)'. With financial data and scheduling data, a cost model and planning will be designed as solutions for realising these possibilities and decision making in practice. This will result in a best practice for a new INDU-ZERO renovation process.

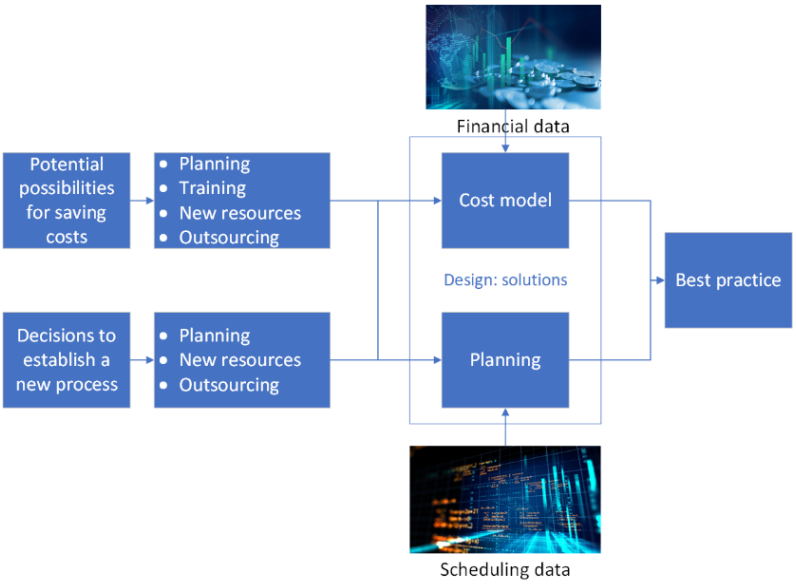

Figure 4.4 Chapter 4 results (cost saving methods & solutions)

4.4 Conclusion

The highest cost items for renovating a house are labour and material costs (82,7%). There is a lot of information necessary on how to save labour and material costs with INDU-ZERO and a lot of decisions need to be made to establish the actual process. For this reason, a format (cost model and planning) for analyzing different scenarios is necessary. Potential cost savings and decisions to be made to establish the INDU-ZERO renovation process were found within the following categories:

- **New resources**, new resources instead of old resources in the process.
- **Training**, adjustments in training employees.
- **Planning**, adjustments in the planning.
- **Outsourcing**, adjustments in outsourcing parts of the process.

A planning and cost model will be used in order to analyze these potential cost savings and decisions and calculate the costs of the final INDU-ZERO renovation process.