ROBOTS AT THE CONSTRUCTION SITE

AN ADJUSTED BUSINESS MODEL FOR CONSTRUCTION COMPANIES

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An adjusted business model for construction companies

Master Thesis

Liselotte Josephine Hoogewerf

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Colophon

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'It is not the strongest of the species that survives nor the most intelligent, but the one most responsive to change'

- Charles Darwin (1809)

PREFACE

A remarkable thing I have learned during my studies is that the construction industry is one of the most traditional and conservative industries. However, as students of Delft University of Technology, we are always expected to come up with revolutionary and innovative ideas, which in my opinion is contradictory. Therefore, I see this as a mission, transferring my enthusiasm and knowledge about innovation to construction companies to illustrate that innovating and constructing can co-exist.

In this thesis 'Robots at the construction site, an adjusted business model for construction companies', innovation is used as a strategy to deal with on the one hand the increasing real estate demand, in particular, housing and on the other hand the growing scarcity of workforce. This topic combines the general knowledge of design and construction management with trends in the field of the construction industry, overall global trends and the current technological developments. The objective of this research is to align the business model of construction companies with the available on-site robot technology. With this study, I aim to complete my Master Management in the Built Environment degree from the Faculty of Architecture with the Entrepreneurship Annotation from the Faculty of Technology, Policy and Management of Delft University of Technology. After a little more than 13 months of hard work, I proudly present this master thesis.

Acknowledgements

Although writing a thesis is, of course, an individual assignment, this work also emanates from the brainstorm sessions with and highly valuable support and critical feedback from the people that have been involved in my master thesis, directly and indirectly. First of all, I would like to thank my both of my mentors Hans Wamelink and Victor Scholten; it was a pleasure to work with both of them. I am grateful for the constructive feedback, the support and help when needed during my entire graduation process, but also for their understanding of all the (BOSS) side-activities and even their advice about how to chair the committee. Secondly, I would like to thank Jurre van der Ven of my graduation company Heijmans. He gave me the opportunity to graduate at Heijmans, shared all his knowledge about innovations and in particular robots and supported me in each situation: finding a suitable robot, looking for a comparative industry, visiting a dairy farm, assisting me during the focus group and even more valuable steering me in this sometimes-unstructured graduation process. Of course, I am grateful to all the interviewees, focus group participants and all the other inspiring professionals in the construction industry and dairy farms for participating in my research. I enjoyed all the interesting conversations. Fourth, I would like to thank my BOSS board, Study Trip committee, (former-) roommates, JC Dief and other friends for their endless support, help and distraction when needed. Finally, my last acknowledgement is directed to my lovely family. I am more than grateful to my parents for giving me the opportunity to study, for all their support during my studies and beyond and for always being there for me! As well as to my dear sister Roseanne, my role model and right-hand man, who after seven years of helping me out during days and nights, also might deserve a degree in Architecture. Without her, I was still crafting my bachelor models!

Liselotte Hoogewerf
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ABBREVIATIONS

AI	Artificial Intelligence
BIM	Building Information Modelling
IoT	Internet of Things
ISARC	International Symposium Automation and Robotics in Construction
Prefab	Prefabricated
R&D	Research and Development
ICT	Information and Communication Technology

GLOSSARY

3D concrete printing robot	An industrial robot which constructs 3D objects by printing cement layer by layer.
3D-printing	A device that can produce a three-dimensional object, by building the object layer by layer, based on a digital design.
Actuator	The driving force of the robot including the locomotion.
Additive manufacturing	3D-printing
Aftercare costs	A budget which is withheld in case there are any defects in construction within the warranty period.
Anything to anyone business	A business which is focused on the cash flow management, by accepting all kind of projects to ensure a continuous stream of work.
Artificial Intelligence	The science that deals with the creation of an artefact that shows some form of intelligence.
Automation	A way to manage a process, in which all tasks are executed by technical tools.
Autonomous robot	A type of robot that can perform tasks independently (to some degree).
Big Data	A phenomenon in which large amounts of real-time data from structured and unstructured sources are collected and analysed.
Building blocks	Nine basic elements, which describes the logic of how a company intends to make money. These buildings blocks include the Value proposition, Customer segment, Customer relationship, Channels, Key activities, Key resources, Key Partners, Cost structure and Revenue streams (Osterwalder & Pigneur, 2010, p. 15).
Building developer	A developer, who also execute some of the construction activities itself.
Building Information Modelling	A digital model that stores, uses, and manages all relevant information throughout the building process and the life cycle stages of the building.
Business case	A feasibility study which predicts the cash flows of a single action or decision alternative.
Business Model	A business model describes the rationale of how an organisation creates, delivers, and captures value (Osterwalder & Pigneur, 2010, p. 14).
Business Model Canvas	A tool to visualise, describe, analyse, and (re)design business models.

Business strategy	A plan for the future of the business, the goals, drivers, competition, technology and the future market.
CAR costs	The costs for the all risk insurance of construction companies.
Casting	A construction method in which floors and walls are poured in concrete, by making use of a framework.
Channels	One of the nine building blocks of the business model canvas, which describes how the supplier get in touch with its customer.
Cognition	Technology domain focused on the human interaction and development of artificial intelligence. The process of acquiring knowledge and understanding through perception.
Cognitive robot	Robots with intelligent behaviour, who can learn, reason and response in complex situations.
Construction site costs	The costs of temporary constructions, which includes construction site equipment and project-based personnel. The total price is highly dependent on the construction time.
Construction site personnel	The workforce which are executing the project on the construction site, such as carpenters (Dutch: CAO-personeel).
Contractor	A construction company. The party who is responsible for the (physical) execution of a construction project.
Controller	The brains of the robot.
Conventional construction practice	The traditional way of building in which separate materials are brought to the construction site where all assembly is carried out.
Cost structure	One of the nine building blocks of the business model canvas, which illustrates all the costs which are made to produce the product or deliver the service.
Cost-driven industry	Industries which are steering on the lowest production costs.
Customer relationship	One of the nine building blocks of the business model canvas, which describes the relation between the product or service supplier and the customer.
Customer segment	One of the nine building blocks of the business model canvas, which describes the target customer of the product or service.
Developer	A party who is responsible for the activities that range from designing concepts for new real estate projects on acquired land to the redevelopment and renovation of properties and the (re)sale of the project.
Developing contractor	A main contractor, who is also involved in the initiation phase by developing own projects on their acquired land, before building.
Direct costs	Costs of materials and work that remain in the constructed property.
Disruptive	The phenomenon that newcomer with a smart idea and technology take over the market share of leading companies and wipe out entire industries.
Drones	Unmanned aircraft.
Earnings model	An earnings model describes how a company makes money.
End-effector	The tool on the end of the robot arm, which can execute the specific task of the robot.
Executive Technical Administrative personnel	All the workforce who are responsible for executive, technical or administrative tasks (Dutch: UTA-personeel).

General costs	The non-project related costs such as the rent or mortgage of the office, the wage of the project manager and administration etc.
Hardware	The physical equipment of a computer system.
Industrialisation	The social and technological re-organisation of an economy for the change of the production process towards manufacturing.
Information and Communication Technology	All the hardware, software products and services and communication equipment and services.
Innovation	The process of translating an idea or invention into a product or service that creates value for which customers will pay.
Integrated contracts	A contract form in the construction industry in which one party is reliable for the entire projects.
International Symposium Automation and Robotics in Construction	ISARC is the only annual conference concerning the field of construction robotics and automation, held by IAARC (International Association of Automation and Robotics in Construction).
Internet of Things	An internet development, where objects will be connected to a network which enables the objects to exchange data.
Key activities	One of the nine building blocks of the business model canvas, which lists the activities needed to produce the product or deliver the service.
Key partners	One of the nine building blocks of the business model canvas, which lists all the partners involved in the production of the product or delivering the service.
Key resources	One of the nine building blocks of the business model canvas, which lists all the human, technical and financial resources needed to produce the product or deliver the service.
Manipulation	Technology domain focused on the field of mechatronics, drives and motion control regarding speed, precision and reliability.
Manipulator	The mechanical body of the robot.
Masonry	A construction method in which non-story high elements are glued or as masonry constructed. In the Netherlands, limestone is the most commonly used material for masonry constructions.
Mechanisation	The replacement of physical human tasks by a machine.
Navigation	Technology domain focused on localisation, mapping and path planning.
Other costs	The costs which cover the general costs, risk/profit, CAR and aftercare (Dutch: Staartkosten).
Outside-innovation	Innovation developed by other parties in the supply chain.
Perception	Technology domain focused on
Pre-fabrication	A construction method in which elements or units are produced in a conditioned environment (factory) and are transported to the construction site where the structure is to be located and were the elements or units are assembled.
Process innovation	The implementation of a new or significantly improved production or delivery method (OECD, 2011, p. 140).
Processor	The brains of the robot.
Procurement	The process of finding a suitable supplier for a specific project, by cross-compare the

	design, cost, or quality of different suppliers.
Product innovation	The introduction of a good or service that is new or has significantly improved characteristics or intended uses (OECD, 2011, p. 140).
Profit/Risk	A cost margin that is calculated on the total project cost.
Project-based business	A business based on one of a kind projects, limited by time and involves hostile relationships with the supply chain.
Revenue streams	One of the nine building blocks of the business model canvas, which illustrates all the different incomes of services and products.
Robot	A robot is a smart, multitasking machine, controlled by a computer which is attached to a movable physical body, which (semi) automatically performs jobs and can react to its environment based on given data, calculations and own observations.
Robotics	The technology branch that deals with the design, construction, operation and application of robots.
Robotisation	The replacement of physical and rational human tasks by a robot.
Row-houses	Housing type originated in Europe, a row of identical or mirror-image standardised houses, with shared side walls.
Sensors	The measurement tools of the robot.
Shell	The construction framework consisting of floors and walls (Dutch: Casco).
Software	The operating program of a computer system that consists of data or computer instructions.
Specials	Unique construction projects, with complex designs, which are custom made.
Standardisation	Implementing or developing a standard, monotonous product to fasten the construction process and reduce costs.
Supply Chain	A complex system of actors, activities, information and resources involved in the whole process of a product or service.
Tender	Competition for a project, in which a construction company prepares a document (based on design, cost, quality etc.) to convince the client to be contracted for a specific project.
Traditional contracts	A contract form in the construction industry in which different tasks are the liability of various actors.
Traditional way of building	The conventional construction practice in which separate materials are brought to the construction site where all assembly is carried out.
Urbanisation	The movement of inhabitants of rural areas to intensively inhabited urban areas.
Value proposition	One of the nine building blocks of the business model canvas, which describes the product or service which a company delivers to its clients.
Wooden skeleton	A construction method in which wooden styles and rules are prefabricated in the factory and are assembled on location.

ABSTRACT

Context - After the recession of 2008, the real estate market is picking up again. Amongst others due to the urbanisation and the increasing world population the real estate demand is growing. However, the current scarcity of workforce in the construction industry might become a huge issue in the future. In order to deal with the future real estate demand, the conventional construction industry needs to change. Although other industries are gratefully using newly developed technologies such as robots, innovations on the construction site are hardly used.

Objective - This thesis aims to investigate how a business model of a Dutch construction company has to change to make on-site robots feasible. This research provides different strategies for construction companies to implement robots for the construction of row-houses, in order to deal with the emerging issues.

Methods - This research is divided into three parts. The first section is a literature review providing an overview of currently developed robots, the status of the construction industry and the business models of construction companies. Secondly, an empirical part in which interviews are conducted to find out what the current business model of Dutch construction companies looks like. In addition, a case study in the dairy industry has been conducted as inspiration. In the final part, the operational section, all gained knowledge is combined and formulated as input values for the design of the adjusted business model. This is validated and complemented through a focus group with experts from the construction industry. For this research, the Business Model Canvas of Osterwalder and Pigneur is used as a framework.

Results - Three different strategies are designed, based on the current business models of construction companies. These proposed models are adjusted to the input of the chosen robot, the case study in the dairy industry and the outcomes of the focus group. In the business model of the first strategy, the construction job is outsourced to a sub-contractor, who responsible for the operation of the robot. Within this model, minimal adjustments are needed for the construction company itself. However, this is the most expensive way to construct. In the second strategy, the robot is also implemented as key partner in the current business model, in this case not as sub-contractor but as a supplier. The robot is rented by the construction company from an external equipment party. This scenario will require adjustments of the current business model. Although this business model is less costly than the first model, it is still more expansive than currently used construction methods. The last strategy implies the purchase of a robot by the construction company itself. The impact/influence on the business model is shown for a worst and a best-case scenario. This strategy will cause several changes within the current business model, of which the most important is the robot as new key resource. The difference in costs depends on the worst or best scenario. The worst scenario, turned out to be the most expensive one, while the best scenario will just have minimal impact on the costs.

Conclusions - Three different strategies are designed with matching business models for the implementation of on-site robots by construction companies. Therefore, it is impossible to develop one generic business models. Hence, the adjusted business models matching to the three possible strategies are based on a merged business model of all the participating construction companies. For each of the strategy, specific adjustments need to be made in the current business model. The first business model, in which the robot will be implemented by a sub-contractor turned out to be the most expensive scenario. Nevertheless, according to the practice, this will be the most promising scenario to start implementing robots. The fact that construction companies take a passive position towards innovations confirms the findings from the literature study that concludes that construction companies are described as traditional and conservative. However, when the urgency for the use construction robots grow, due to an increasing shortage of workforce, it is more likely that the last strategy will be implemented; the purchase of a robot by the construction company itself. This will be the most obvious one, regarding costs, efficiency

Keywords - 3D concrete printing robot, business model, business model canvas, Dutch construction companies, innovation, on-site robots, row-houses.

SUMMARY

Introduction

The construction industry is one of the oldest industries in the world and represents the largest economic sector in European countries (Deloitte, 2016). Therefore, innovation in such a large economic sector is important, since this will increase the likelihood of a growing economy (Blayse & Manley, 2004). However, compared to other manufacturing industries, who moved towards automated and robotised processes, the construction industry is rather conservative and traditional. The methods used in the construction industry have hardly changed. Due to a lack of research and developments (R&D) trends as automation and robotisation have barely been applied (ABN AMRO, 2016; Balaguer, Gonzalez Vıctores, Jardon, & Martınez, 2013; Abderrahim & Balaguer, 2008).

Currently the need for change slowly starts to penetrate the sector, now the construction market is finally picking up again (ABN AMRO, 2016). The construction freeze during the recession together with the rapid urbanisation, has resulted in a lack of (affordable) housing, especially in inner cities (Elattar, 2008). Therefore, housing will be the biggest construction task for the upcoming years (Maas & van Gassel, 2005). However, the increasing shortage of workforce, together with the low productivity makes it impossible for traditional construction companies to meet the future real estate demand (Peiffer, 2016) (Halpin & Kangari, 1990). Furthermore, the construction industry should be aware of their competition from other industries and newcomers, who start entering the construction market with new innovative ways of constructing. If the traditional construction companies do not take advantage of the current trends and innovations, and they do not renew their business model, this can be disruptive for these traditional construction companies (ABN AMRO, 2016).

There are potential technological trends which can be used as a strategy to deal with the occurring issues in the construction industry. BouwKennis (2016) investigated which currently developed technologies and innovations are expected to have a huge impact on the construction industry in the upcoming years and which technologies will be the most applied within one year. For the realisation phase 3D-printing, Robotics and Drones are expected to be promising. Taking the automated and robotized manufacturing industry as an example, together with the measures Japan undertook to deal with the lack of workforce and following the current technological trends, it can be stated that robotisation can be used as strategy to deal with the increasing shortage of skilled construction workers, the low productivity and efficiency of the construction industry and the increasing demand for real estate developments.

Problem statement

Innovation becomes possible when there is a need-based feasibility, technical feasibility, and economic feasibility. Even though the first two are proven, the latter has not been researched. Because of this, the economic feasibility must be proven, before on-site robots will be implemented for large-scale production. With the use of a business model, the different ways of implementing on-robots, as well as the economic feasibility of robots can be demonstrated. However, in the current situation a suitable business model is not existing.

Research objectives

This research aims to explore the ways a business model of a Dutch construction company have to change in order to make on-site robots for large-scale production possible. The outcome of this study will be an adjusted business model for large Dutch construction companies. By means of a business model the different ways to implement robotization as future strategy will be illustrated. In addition, the economic feasibility of robots will be calculated as part of the business model.

Research questions

This research gives answer to the following question:

*'How can **Dutch construction companies** adjust their **business model** in order to make **robots** at the **construction site** possible?'*

Conceptual model

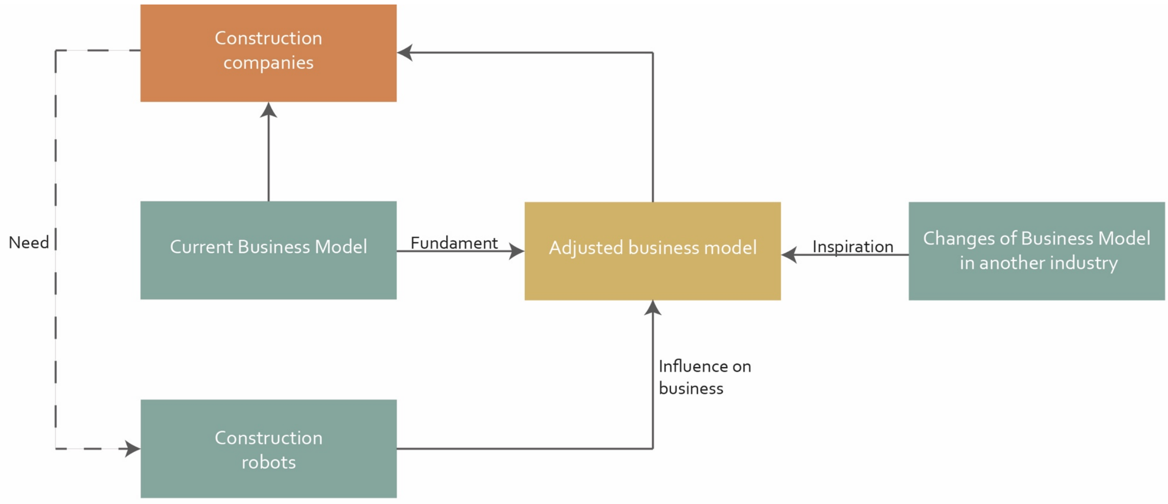

Figure 1 Conceptual model (Own Image)

In the upcoming years, the need for robots in the construction industry will increase, due to the growing shortage of construction workers, the low productivity and efficiency and the emerging competition. Although the technology is already developed, the construction companies cannot implement robots in their current business model. Therefore, an adjusted business model needs to be designed, with the current business model of construction companies at its base and taking in to account the influence of the chosen robot on the construction process. While designing an adjusted business model changes that had to be made in the business model of another industry due to the implementation of robots, will be used as inspiration.

Robots for construction: State of the art

In 1920, the term robot is used for the first time by the writer of a futuristic play. This term was derived from the Czech word 'Robota' which indicates monotonous work, drudgery and servitude (Wikipedia, n.d.). However, nowadays there is no consensus about the definition of a robot. For this thesis, a definition has been composed, based on the different definitions and subscriptions in literature:

A robot is a smart, multitasking machine, controlled by a computer which is attached to a movable physical body, which (semi) automatically performs jobs and can react to its environment based on given data, calculations and own observations.

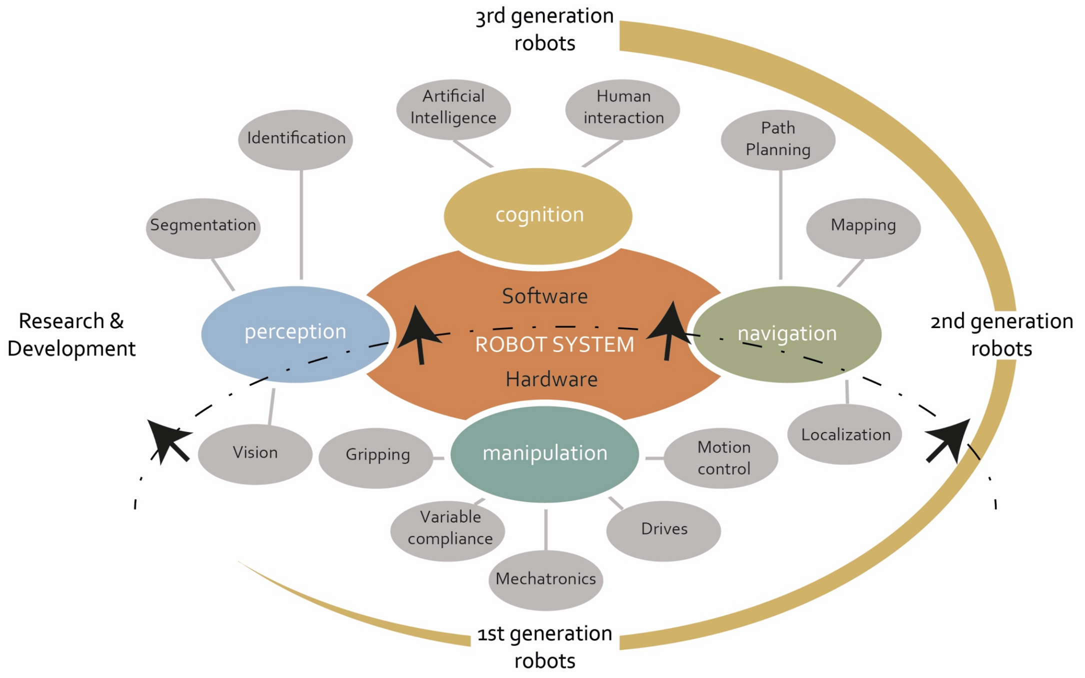

Figure 2 State of the art of the four technological domains (Brabantse Ontwikkelings Maatschappij, 2015, p. 26)

The state of the art of robots can be explained according to the software and hardware developments, as illustrated in figure 2. Currently, second-generation robots are on the market. These robots are able to execute simple but heavy tasks in an accurate way (Brabantse Ontwikkelings Maatschappij, 2015). In comparison with the software of the first-generation robots, their intelligence has increased to an autonomous level. Besides, the perception and navigation are improved by means of vision-systems, GPS and gyroscopes (Brabantse Ontwikkelings Maatschappij, 2015). The hardware developments have mainly focused on the increase computer power, in order to make new applications of robots possible. The combination of multiple tasks and a highly unstructured environment such as the construction site are not yet programmable (Rouwenhorst, 2016).

Robots for the construction can be divided into on-site and off-site robots. Off-site robots are already widely used in the prefabrication of housing. Within these robotised factories, prefabricated elements of dwellings are produced in a highly accurate way (Bulusu, 2015). On-site robots are employed on the construction site. According to literature 15 tasks can be executed on the construction site (Bock, 2007; Bulusu, 2015; Elattar, 2008): Assembly, building skeleton erection, coating of fire protection on steel, concrete compaction, concrete distribution, earthwork, indoor plastering, interior finishing, lifting heavy elements, masonry, removal of old coating, road paving, surface finishing, welding, window glass mounting.

Robots are expected to solve the shortage of workers, improve the productivity and efficiency in the construction, will increase safety and health conditions of construction workers, improve the quality and accuracy of buildings, make a shift possible from mass production to mass customization and lastly will construct in a more sustainable way (Peiffer, 2016; Elattar, 2008; Kangari, 1985; Brabantse Ontwikkelings Maatschappij, 2015; Yagi, 2006)

However, there are also concerns about the implementation of robots. The biggest fear is for the unemployment of humans. Although some predict that robots will only cause a shift in jobs, some argue that especially the low-educated population will become unemployed. Additionally, construction companies will be more dependent on electricity instead of workers. Finally, the liability and legislation of robots for construction are not established yet (Bowles, 2014).

Although the construction industry starts using robots, mainly industrial robots developed for other industries are used, such as the automotive industry which is the biggest supplier of industrial robots (International Federation of Robotics, 2016). Other industries who have a big share in industrial robots are the electric, metal and chemical industries. The (mobile) service robots are most sold to the logistic, military, field and medical sector (International Federation of Robotics, 2016). In the Netherlands, in particular, the dairy farm is the major consumer of service robots (Brabantse Ontwikkelings Maatschappij, 2015).

Dutch construction companies

The Dutch construction industry is a highly-fragmented industry, with 156.000 companies operating in the fields of civil engineering, infrastructure and real estate construction (Hompes & Rijt, 2010; Bouwen Nederland, 2017; Wikipedia, n.d.). While the small construction companies are mainly focused on one specific discipline, the largest companies operate in multiple fields. However, each department is, in general, its own independent entity within a construction company. In the residential sector, different kinds of housing are constructed of which row-housing is the most standardized product.

Traditionally, large construction companies were only involved in the realisation phase, where they were responsible for the construction itself. However, their role shifted from contractor to a more management-oriented company. Instead of having all the carpenters in-house, they started hiring several specialized sub-contractors in order to become flexible and increase the efficiency. In addition, they gained more space in the construction process. By bringing parties together and taking care of the risks, construction companies got involved in all the life cycle phases of buildings. Furthermore, forward integration made it possible for construction companies to take care of the development of their own construction project. However, they only developed to ensure their own construction consistency (Dorée & van der Veen, 1999). This is in contrast with small or medium-size companies which are generally only focused on the construction itself and still have carpenters in-house (Loosen, 2002).

For the construction of row-houses different methods are used (Bongers, 2007): Casting, Masonry, Assembly of the wooden skeleton, Prefab Elements and Prefab units. Currently, wooden skeletons are hardly used for housing projects within the Netherlands. The choice of a specific method is based on the design of the project, the location, the number of replications, the budget of the project, the in-house knowledge of the construction companies and the available equipment. In addition, the construction method does not only influence the construction time and the cost of the project, but also the flexibility and adaptability of the design and the number of actors involved (Bongers, 2007).

Business model of construction companies in theory

There is no consensus about the definition of a business model, neither about the fixed components. In this thesis, the definition of Osterwalder and Pigneur (2010) is used: *'A business model describes the rationale of how an organisation creates, delivers, and captures value'.* Each company has either an implicit or explicit business model, which explains the way a company captures the value of its activities. One business model can be applied to an entire company, but it can also be product specific. Business models can help capturing the maximum (financial) value of innovations, and by means of a business model a new technology can be commercialised. (Rosenbloom & Chesbrough, 2002). However, the business model itself can also innovate by means of an improved process, another value proposition or revenue model. In addition, a business model can be used as a tool to visualise, communicate and discuss the vision of the company (Pekuri, 2015).

Recently only one study is done to the business models of construction companies. Pekuri (2015) conducted several interviews to gain insight into the business models of construction companies in Finland. In his research, he explains that the construction industry is a project-based business, with a large supply chain, which makes this industry risky and reactive (Mokhlesian & Holmén, 2012). The innovations that has been implemented are technologies developed by other supply partners (out-side innovation). In order to facilitate innovation, it is important for managers to understand the business model because this will provide a starting point for construction companies to innovate. In addition, the unawareness of the business model will reduce the effectiveness and hinder performance (Höök & Stehn, 2014). As a result of Pekuri (2015) his research, it can be stated that there is no general definition of business models in the construction industry, not between different companies and neither within a company similar descriptions are given. Furthermore, the use of business models in construction does not correspond with the literature. According to the literature business models evaluate the suitability of a project within a company. However, since the construction is a project-based business, they rather focus on a cash flow stream by acquiring enough projects, than being selective. Therefore, the construction industry is seen as 'anything to anyone' business (Pekuri, 2015), as illustrated in table 1.

Value creation system	Value proposition	Revenue model
Human resources and qualifications	Lowest cost	Payment according to contract and progress
Tender preparation	According to the plan	Change orders
Financial resources	No defects	Additional work
Construction management	References	Financing form client

Table 1 Traditional anything to anyone business model (Pekuri, 2015, p. 57)

Business models in construction are used to reach financial goals and acquire work, instead of creating value for customers. Pekuri (2015) concluded that there is no general business model for construction companies available. Although the definitions and elements are different, there is no single unique characteristic. Therefore, it can be stated that construction companies have rather similar business models.

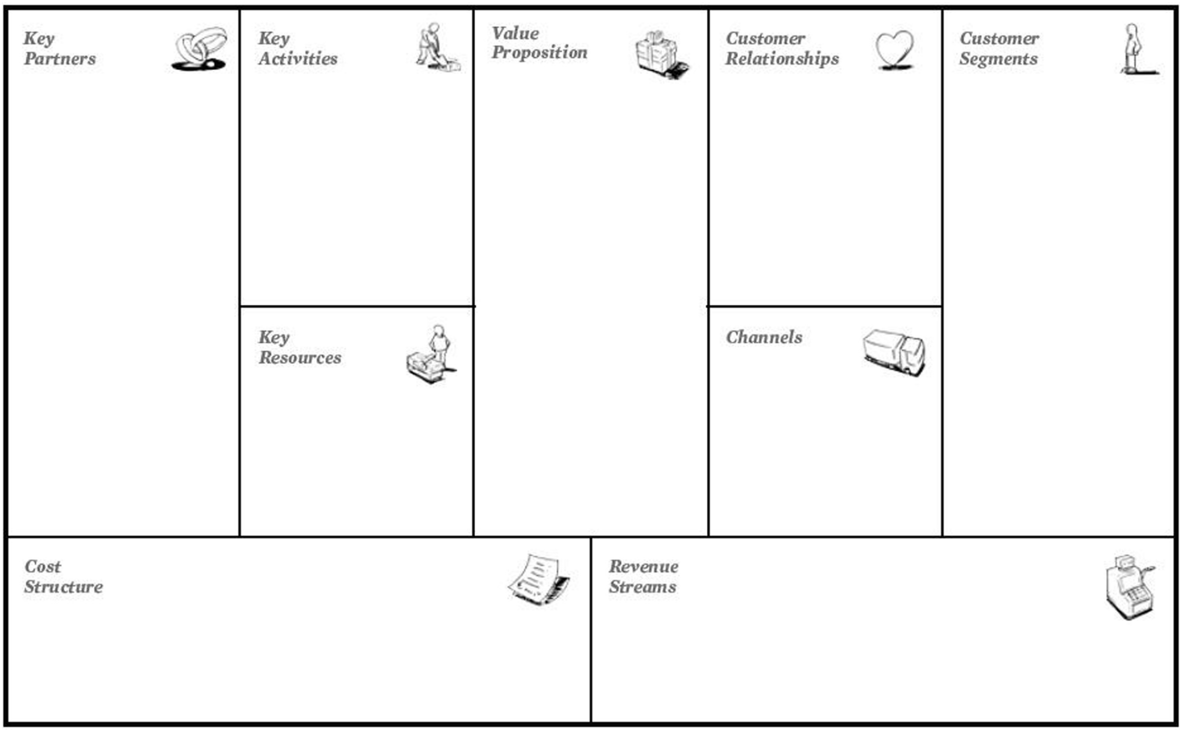

Figure 3 Business Model Canvas (Osterwalder & Pigneur, 2010)

In this thesis, the business model canvas of Osterwalder and Pigneur (2010) is used as framework to make the business model of construction companies explicit and to design an adjusted business model. This canvas consists of nine building blocks: the value proposition, customer segment, customer relationship, channels, key activities, key resources, key partners, cost structure and revenue streams.

Methodology

This research is a hybrid research. It consists of both an empirical and formal research part. For this research, the business model canvas of Osterwalder and Pigneur (Osterwalder & Pigneur, 2010) is used as framework.

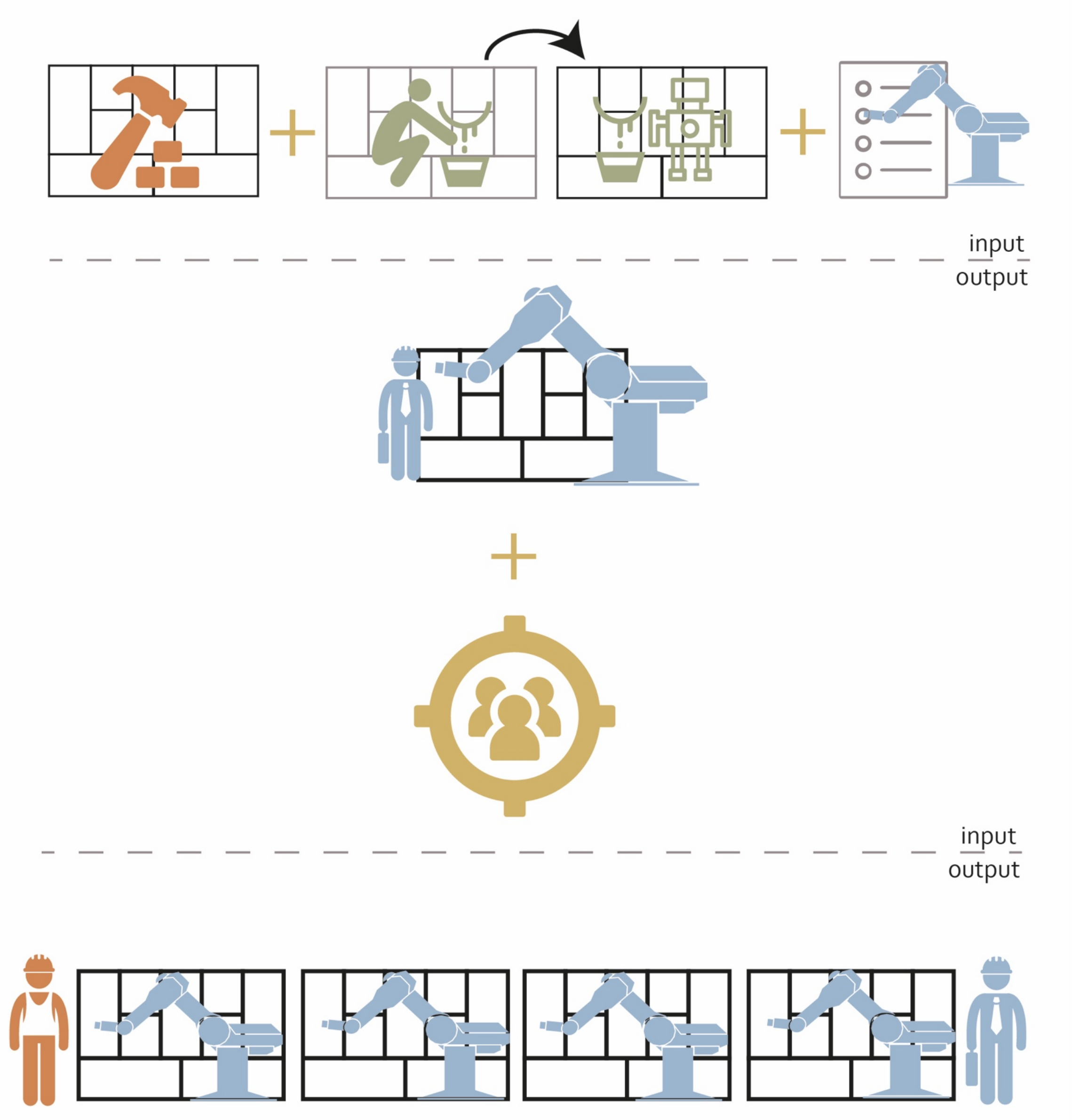

Figure 4 Input for the adjusted business model (Own image)

Three different steps in this research can be distinguished. First, a literature study is done, to understand the state of the art of robots for construction, to find out how Dutch construction companies operate and to investigate the business model of construction companies. In the second part, empirical research is done to the currently used business models of large Dutch construction companies by means of semi-structured interviews. A case study is conducted in the dairy industry, and explorative interviews are held with the developer of the selected robot: a 3D concrete printing robot. This part together with the literature review is the input for the third part: the formal research. In this part, an adjusted business model is designed based on the input of the first two parts. The first draft of the adjusted business model is reviewed by a focus group consisting of Dutch construction professionals upon which the final business models are designed to make the employment of robotics possible on-site.

Business model of construction companies in practice

The findings of this chapter are based on interviews held with seven large construction companies and one medium size construction company in the Netherlands. Construction companies found it difficult to define a business model. In general, they compared a business model with an earnings model. In addition, some construction companies added that a business model includes the value of a product or service that is offered to the customer, that a business model shows how a business sustains and that explains the field in which a company operates. Companies that participated in this research with multiple interviewees did not give a similar definition of explanation of a business model.

All of the interviewed companies are using their business model to select projects. Although during the crisis, construction companies indeed operated as 'anything to anyone business', to ensure continuity, they now appear more selective. Currently, since the market is healthy, most construction companies try to avoid procurements based on the lowest price.

Based on the analysis of the business models of the interviewed construction companies, it can be stated that none of the construction companies had an unique element. The business models of consist of different combinations of elements, this is what distinguishes the models. In addition, the chosen construction method influences the business model; the value proposition changes, other customer relations can be used. The own share of the construction process influences the key activities, and thus the key resources are adjusted when choosing for another construction method. In addition, the numbers of key partners are dependent on the method used, as well as the related costs. When the activity and thus the own contribution to the process increased, or decreased, the revenue will change.

However, in general, independent on the method the following business model can be composed: A construction company proposes row-houses to clients. Usually, these clients are not the end users of the building, but an external or internal business. Here, a relationship is established with, in any case, the initiator of the project. The agreements made, are stipulated in a contract. Dutch construction companies are largely involved in tender and selection procedures, to acquire work. The changing role of the contractor becomes clear when looking at the key activities of the construction company. They aim to organise, manage and bring together all several partners, who then perform the executive tasks within the construction process. The number of partners and own activities determine which internal resources are required to build the house. All partners, internal employees, materials, and equipment must then be paid. These costs are divided into direct costs, general construction costs and other costs. Ultimately, the house and the service of the construction company provide income. This makes the construction industry profitable.

The influence of robotisation in another industry

The dairy industry is taken as an inspirational case study in this research. Since the nineties developments for robotisation in this industry started, with the aim to increase the productivity of this sector. This sector is dealing with similar issues as the construction industry. The heavy working conditions in this industry and the bizarre and inflexible working hours have caused a shortage of employees. In addition, the high labour intensity and the increased wages in this sector have caused growing production costs (Galen, Bakker, & Beers, 2011; Hogeveen & Heemskerk, 2006; Brabantse Ontwikkelings Maatschappij, 2015).

Currently, Lely has developed twelve products to facilitate the feeding, milking, increase the health and hygiene of the cows and pamper the cows. These products are interconnected with each other by an application, in which data is gathered and analysed. Lely is not just purchasing and leasing robots, but also provides the service and maintenance of the robots.

Due to the implementation of the robot, the following changes in the business models of dairy farms occurred: First of all, robotisation in the dairy industry is a process innovation; the product remains unchanged. However, the cow welfare increased and due to the efficiency farmers can start a side-business. The customer segment, relationship and channels do not change, Friesland Campina is the only customer of these dairy farms. Significant changes took place in the building block key activities. Here it becomes clear that the physical labour of the farmer is taken over by robots. In case of Dairy Farm 1, this means that there was room for additional business. The productivity of the companies has also increased significantly. This is at least doubled (Dairy farm 1) or is even six-fold. Where the farmer and his staff were initially responsible for physical work, they shifted towards a more management role, in which they analyse the data gathered by the robots, by means of the Lely application. Due to the advent of different robots and the application, the key resources have changed. As a result, with the same number of workforce, more milk cows can be held (Company 1), or with the same number of cows, fewer employees are needed. In both cases, less manure is required to produce a litre of milk. To enable robots, in both cases a modified milking parlor had to be built. In the building block Key Partners, a new service partner is added. Lely is not just the seller of the robots, but will also be a service partner. The changes in activities, resources and partners have caused a shift in the cost structure. The cost of the mortgage (equipment) and service has risen, on the other hand, it can be said that labour costs have fallen. At Dairy farm 2, the difference in labour costs is extreme; they save 3 to 4 cents per litre of milk. Over the years, the milk price has barely increased. However, the overall revenue has risen sharply, along with the productivity. To make sure that the total revenue would grow, they have calculated the entire business case to find out what the break-even point of this investment was.

3D concrete printing robot

For this research thesis, the Cybe 3D concrete printing robot has been chosen; this robot produces concrete elements on the construction site. Only two construction workers are needed to operate the robot and construct walls. Cybe developed three products, which together are able to construct several kinds of frameworks, walls, sewer pits etc. The first product is the hardware; a concrete nozzle is attached to a mobile automotive factory robot, which can be driven by an interface and is attached to a mix-pump system. Second, software programs have been developed to drive the manipulator. Last, Cybe developed its own fast-drying cement, Cybe Mortar. Since the robot is placed on a caterpillar, heights until 4,5-meter height can be reached. However, when a larger caterpillar is used, even higher elements can be produced. The 3D printed construction has been investigated by Witteveen and Bos, according to their measurements, the elements meet the Dutch construction regulations. However, for the reinforcement needs to be added while the construction is wet. In addition, wires and pipes can be integrated into the walls, during construction.

Adjusted business model for construction companies

There are three different sources of data used as input for the adjusted business model of construction companies to make on-site robots possible: the current business model of construction companies, the changes which occurred in the business model of dairy farms and the features of the chosen robot. In addition, the input and validation of a focus group with experts has taken into account when designing.

There are three different strategies in which robots can be implemented. The robot can be introduced by a new sub-contractor who takes over the whole job (strategy 1), the robot can be hired as external equipment service by a supplier (strategy 2), or the robot can be purchased by the internal equipment department of the construction company (strategy 3). Each scenario brings difference changes with it.

Value proposition

In all the three scenarios, row-houses will still be the main product of a construction company. Nevertheless, a shift to a flexible and custom made design will be the result of 3D concrete printing robots. Since they are able to construct complex and unique designs. Even in a late stadium, changes to the design can still be made. Therefore, robots are not only seen as a process but also product innovation.

Customer segment

Since construction companies will still produce row-houses, the clients will not change. However, the flexibility will be more used by initiators who construct owner-occupied houses, since a specific customer made rental property is not in first instance necessary for a housing association or investors. In addition, this eventually can make it harder to find second-generation tenants. Even though this will be highly valuable for the individual customer, but most of the largest companies do not construct individual products.

Customer relationship

The customer relationship does not change that much in each of the scenarios. However, due to the increase of customer made possibilities, a higher customer involvement is required in case of co-creation.

Channels

The channels stayed unchanged in all the scenarios. It is good to mention that 3D printing can have a positive influence on the marketing.

Key Activities

The key activities are changing according to the different strategies. In strategy 1, the robot will be used by sub-contractors, who execute the complete job. Therefore, in this strategy, no change will occur. In strategy 2, where the robot will be hired from an external party, own employees have to operate the machine. Therefore, a bigger share in the construction process will be obtained. Also, knowledge of engineering is required, since this will be an extra activity. This also applies to strategy 3. In addition, in the best-case scenario, the employees who are operating the robot are also able to do the plastering, wiring and piping while printing. Therefore, the share in the construction process will even be larger.

Key Resources

For all the strategies, it is applicable that the production of an own prefab factory will slow down, just floors are still required. Given the shortage of construction workers, the robotised construction robot will ensure the construction continuity, since there are only two employees needed. Strategy 1 will hardly have an impact on the key resources. Only fewer internal carpenters are needed for the construction of walls. However, the construction of the walls is only a small part of the total construction process and will thus minimally influence the human resources. In strategy 2, the own employees have to be trained, or new ones with knowledge of robotics need to be hired. In addition, new software needs to be discovered. In strategy 3, the equipment department is purchasing a robot. Therefore, an equipment department is crucial. In addition, same changes as to strategy 2 apply. However, for the best-case scenario, the operating team needs to be trained not just in operating the robot, but also in the plastering, piping and wiring activities. To calculate the construction, an internal constructor is recommended.

Key Partners

For all the strategies, it is applicable that the production of an external prefab factory will slow down. However, floors are still required. For all the strategies, the key partners will change. In strategy 1, a new sub-contractor will be added, who is executing the wall construction job. In this case, less external assembly workers might be needed. In case of traditional construction, no masons for limestone constructions are needed, neither are suppliers of limestone. In strategy 2, where an external equipment service will be added with a robot, the same changes will happen. In addition, a supplier of reinforcement is needed, an external equipment party for a construction tent is needed, and a supplier of fast-drying cement is needed. In strategy 3, a service supplier of the robot is added for the maintenance of the robot. However due to the increasing share in the construction process and the executing of piping, wiring and plastering fewer sub-contractors are needed.

Cost Structure

		Traditional project	Prefab project	Strategy 3 BCS
Total price difference		100 %	97,3%	103,7 %
Direct costs	Labour	8,2%	5,4%	11,3 %
	Material	17,5%	11,6%	14,7 %
	Equipment	0,9%	0,3%	6,5 %
	Sub-contracting	47,5%	61,1%	42,2 %
General construction site costs		16,7%	12,5%	16,6 %
Other costs		9,2 %	9,2 %	9,2 %

Table 2 Relative cost structure strategy 3 BCS (Based on the numbers of Heijmans and own calculations)

Due to the different changes, the cost structures will also vary. In strategy 1, one expensive sub-contractor is added who is executing all the jobs. Therefore, this scenario turned out to be the most expensive. In strategy 2, the robot will be rented. However, cement, reinforcement etc. need to be purchased. This strategy turned out to be less expensive as strategy 1. Strategy 3 turned out to be the cheapest for the best-case scenario but is still 3 percent more expensive than the traditional construction method. There is a big difference compared to the other two strategies; this is caused by the development of own cement and the increase in productivity due to the increasing share in the construction project. These new strategies compared with the traditional one has mainly shifted cost from the labour costs to the sub-contracting item of direct costs. In general, the construction time remains the same. Therefore, the general construction site costs have not changed in three of the four strategies. Only in the worst-case scenario of strategy 3, the general construction costs slightly increased, due to the longer construction time.

Revenue Streams

The revenue streams are based on the own share in the project. Therefore, strategy 1 has limited influence. In strategy 2, more is executed by the construction company, but the largest influences will be seen in strategy 3 since in this scenario the share of the construction company will be the largest.

Discussion

This research is based on findings in literature and practice. Although overall findings of literature are confirmed by practice, some findings differ. Due to literature, it was expected that a lot of robots were developed for construction and that the development of AI was already far enough developed to be implemented, but this is not the case in practice.

Also, the size of medium and large size construction companies did not have a huge influence on the way a company operates; the participated medium size company in this research is only lacking an internal equipment department and in-house developer. Besides, Dutch construction companies are using their business model for selections, and therefore they cannot be categorised as 'anything to anyone' business. It was expected that one generic business model could be composed, but it turned out that the business models of construction companies all differ. They are using the same elements, but the different combinations make them all unique. The inspirational case study is done in a completely different industry, although the reasons to implement robots were similar the kind of innovation was different. In the dairy industry robots are used as process innovation, while the robots in the construction will change both the process and the product.

The outcome of this research are three strategies illustrated in a business model canvas and a business case is calculated. However, the business case does not demonstrate a break-even point, since it only calculates the feasibility of one project. Costs such as WIFI, water, electricity, education for the operational team of the robot and additional costs for a contractor are excluded from this research. Last, the 3D concrete printing robot can be used for other construction purposes, this is not taken into account in this research. Also, flexibility as added value. It will react on the scarcity of workforce, construction will be independent on the weather conditions and adjustments in the design can be made at the last moment. According to the practice, the first strategy in which the robot will be implemented by a sub-contractor is the most likely strategy. Since the focus group is held before the cost calculations, their opinion might have been different, because strategy 3 turns out to be the most financially feasible strategy.

Conclusion

There is not such a generic business model, which can be adjusted to make on-site robots possible. However, based on the current business model, a case study in the dairy industry and input and the validation of a first drafted business model have led to three possible strategies in which robots can be implemented on the construction site.

In all the three strategies, the flexibility increases due to the implementation of the robot: the adjustments to the design can even be made just before construction, the construction industry becomes less workforce dependent, which is important due to the increasing scarcity of construction workers and in each weather, circumstance the construction can continue, since the robot can be placed in a construction tent. In general, the three strategies the customer proposition, the customer segment, customer relationship and channels change in the same way. Due to robotisation, a higher level of co-creation becomes possible. This means that the end-user of initiators is early and more intense involvement in the process, in order to build a house according to their demands. However, the customer segment remains unchanged. Besides, a 3D constructed house can be branding for the construction company. The other five elements of the business model changed according to the specific scenario. However, it can be stated in general that construction with a 3D concrete printing robot is at this moment not faster neither cheaper than the traditional or prefabricated construction method.

In the first strategy, the robot will be implemented as a key partner. A new kind of subcontractor enters the market and construct the wall on-site with a 3D concrete printing robot. Therefore, a key partner will be added. However, the construction company will remain a manager and therefore fewer changes will occur in the existing business model. Due to the high sub-contracting costs, this scenario is 23 percent more expensive than the regular construction method and 27 percent costlier than prefab.

In the second strategy, the robot will be implemented again by a key partner, but this time as a supplier. The robot will be rented as equipment. Since the construction company will employ the robot themselves, human resources have to be trained. In addition, the required construction materials need to be purchased; such as cement and reinforcement. In this strategy, the construction company is still flexible to choose a construction method, since the robot is externally hired. The costs of in this scenario will be 20 percent more expensive than the traditional and 24 percent more expensive than prefab. The balance of costs shifts more towards the labour costs since the construction company itself will execute the work.

In the last strategy, major changes occur. The internal equipment department of the construction company will purchase a robot, by means of a mortgage. The company will rent the robot of the internal equipment services and will operate the robot self. In addition, a service contract will be designed. Again, human resources need to be trained or new employees need to be hired. In this strategy, the construction company will have an increasing share in the execution of the construction process. For the calculation, a worst and best-case scenario is calculated, based on the occupancy rate and thus the day price to rent the robot. In addition, in the best-case, an own developed cement is taken into account and its assumed that the operation team of the robot can do plastering, wiring and piping activities while printing. Which increase the efficiency of the work. For the worst-case, this resulted in an increase of construction cost of 25 percent compared to the traditional and 29 percent to the prefab method. For the best case, this is only a difference of respectively 4 and 7 percent. The price difference takes place in the equipment and sub-contracting costs.

In all three scenarios, the cost of the construction process will be higher, so that currently the 3D concrete printing robot will not compete with the traditional or prefabricated construction method. Therefore, a great urgency is needed. Based on the different business models, the last strategy in which a robot will be purchased is financial most beneficial and efficient and will increase the flexibility regarding planning, when the scarcity of workforce increase.

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A RESEARCH PROPOSAL

1 INTRODUCTION

This chapter comprises the research proposal. It includes a brief introduction to the research topic and the problem analysis. Furthermore, the relevance and objective of this research will be explained and the research questions will be stated. This chapter concludes with the research design and a reader's guide.

1.1 Background

1.1.1 Current status of the construction industry

The construction industry is one of the oldest industries in the world and represents the largest economic sector in European countries, with a contribution of 9,6 - 11,4 percent to the GDP (Deloitte, 2016, p. 13). Although other manufacturing sectors moved towards more industrialised and automated processes, the methods used in the construction industry have hardly changed over the last centuries. Moreover, the 'traditional way of building', a building process where all the materials are brought to the construction site and are assembled on location, is still the most used construction method. Due to the lack of research and developments in the construction industry, promising trends like automation and robotisation have barely been applied (ABN AMRO, 2016; Balaguer, Gonzalez Vıctores, Jardon, & Martınez, 2013; Abderrahim & Balaguer, 2008). However, according to Blayse and Manley (2004) innovation in such a large economic sector is important, since this will increase the likelihood of a growing economy.

The low level of innovation in this sector can be explained by the insufficient financial resources, the lack of communication between academia and practice and the complexity of the industry. First, the inadequate financial resources which relate to the nature of this industry. In this competitive industry, work is mainly acquired by tenders on the lowest bid (Pekuri, 2015). Especially during the recession in 2008, construction companies assigned for projects with unrealistic low offers to ensure a workflow. Therewithal, the margin in this sector has always been little (ABN AMRO, 2016). This results in poor investments in R&D (Blayse & Manley, 2004). Second, research that has been done on promising trends and innovations, such as robots and automation, has not been communicated between researchers and the practice (Dulaimi, Ling, Ofori, & De Silva, 2002). Last, the highly unstructured projects, the massive objects which need to be built with high accuracy, the low level of standardisation, the medium level of prefabrication, the large supply chain and the high number of involved actors, make this complex industry difficult for automation or robotisation. Hence, the construction industry is seen as traditional and extremely conservative (Bulusu, 2015).

Meanwhile, the construction industry has slowly incorporated developments in other sectors. Numerous new materials that have been developed the last fifty years are applied in construction projects and the on-site labour is diminished and the work conditions are improved due to the accelerated mechanisation (Balaguer, Gonzalez Vıctores, Jardon, & Martınez, 2013). In addition, a quarter century after the start of ICT developments, Building Information Modelling (BIM), a way to digitalise the building process, is only integrated into half of the Dutch construction companies' business strategy (ABN AMRO, 2016).

1.1.2 The need for change

Currently, the construction market is changing. After the recession of 2008, the real estate market is finally picking up again, which has led to the creation of many new jobs in the construction industry. On the one hand, the construction freeze during the recession and on the other hand the rapid urbanisation has resulted in a lack of (affordable) housing, especially in the inner cities (Elattar, 2008). With the forecast that half of the world population will live in cities, housing will be the biggest construction task for upcoming years (Maas & van Gassel, 2005). However, due to the increasing scarcity of skilled construction workers and the low productivity, it will be impossible to for the traditional construction companies to meet the future real estate demand. Meanwhile, the booming real estate market creates opportunities for, the innovative ways of constructing, developed by the new competitors in the construction industry. Hence, the need to change slowly starts to penetrate the construction sector (ABN AMRO, 2016).

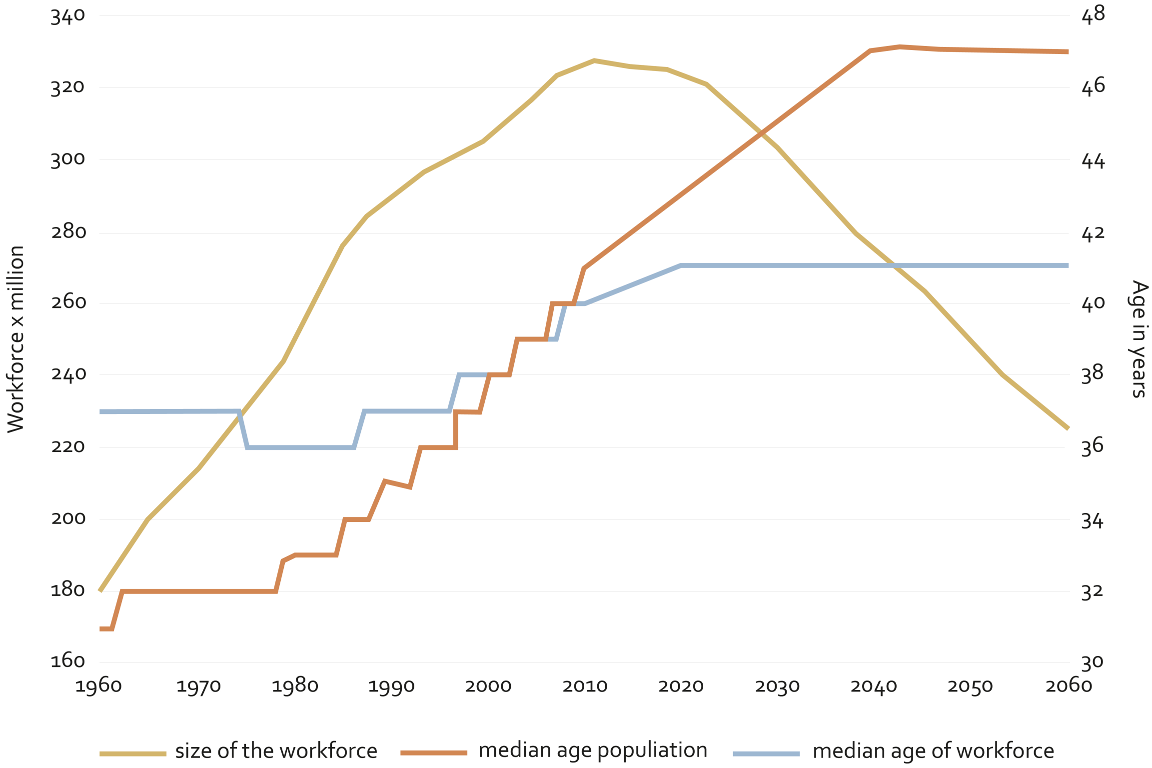


Figure 1 Forecast of world's workforce (Gassel, 2010, p. 73)

The scarcity of workforce is caused by three reasons. First, due to the unemployment during the construction freeze, a significant number of experienced construction workers left the construction industry. Second, despite the significantly increased wages, young people are changing their labour-intense job, for an office career (Peiffer, 2016). This can be argued by the poor and unpleasant working conditions, the intensity of the job, the exposure to noise, dust, radiation, extreme temperatures and high pressure, which can be hazardous to health. Besides, the construction industry is assumed as one of the most dangerous working fields (Halpin & Kangari, 1990). Last, the ageing world population, which in general causes, a decrease of workforce, as illustrated in Figure 1. According to van Gassel (2010), the workforce in the Netherlands will decrease likewise; a reduction from 11 to 10 million of workers is expected.

However, the lack of workforce is not a new issue. America and Japan already had to deal with a shortage of workforce. In America, large organisations and corporations sponsored a training program, to educated new construction workers to prevent the vanishing skills of carpenters, but this was without any success (Halpin & Kangari, 1990). In Japan, the ageing population have led to the development and implementation of automated robots, who nowadays are already employed in several businesses (Bock, 2007).

Moreover, the low productivity and efficiency in the construction industry exacerbate the shortage of construction capacity. The construction industry is a highly labour intensive industry. Therefore, the labour costs significantly influence the total costs of a project (Kangari, 1985). While the productivity of other manufacturing industries increased over the years, with the advent of automatization and robotics, the productivity in the construction industry decreased, as illustrated in Figure 2. According to the Dutch Platform Logistics in Construction (Platform Logistiek in de Bouw, 2014), work productivity of Dutch construction workers decreased to 40 – 50 percent.

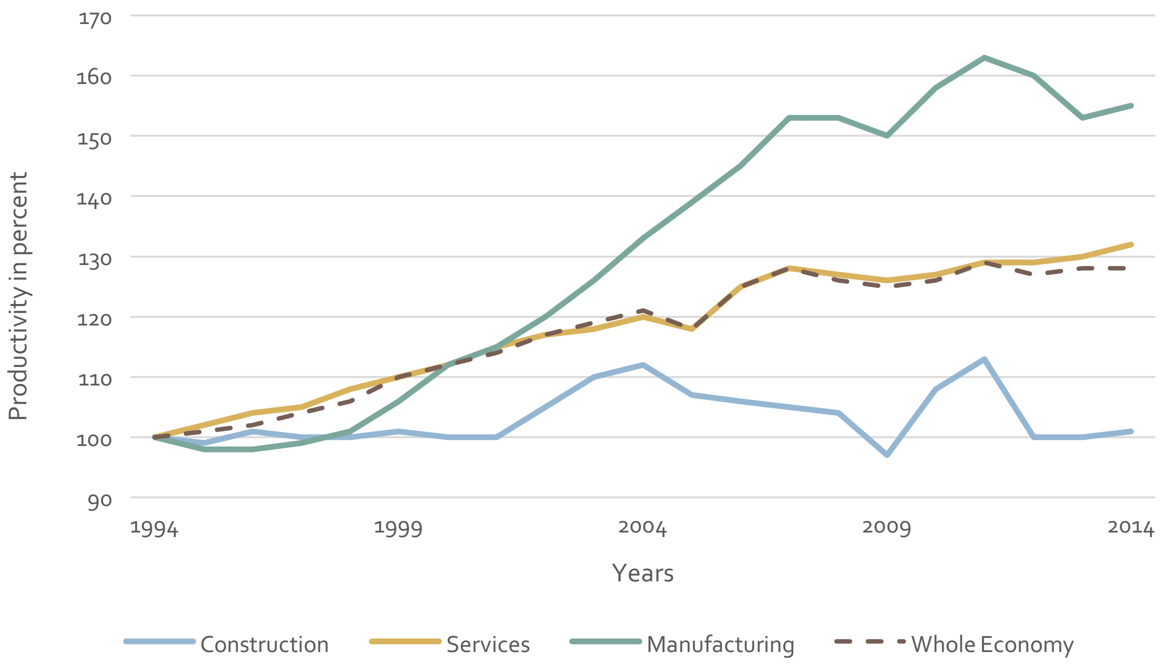


Figure 2 The productivity of different sectors in the UK (The Chartered Institute of Building, 2016, p. 8)

Furthermore, construction companies should be aware of their competition from other industries and start-ups, which are ahead with the implementation of new technologies. With the attracting real estate market, the so-called 'disruptors' start entering the construction market with their new innovative ways of constructing. If the traditional construction companies do not take advantage of the current trends and innovations, and they do not renew their business model, this can be disruptive for these traditional construction companies (ABN AMRO, 2016).

1.1.3 Potential technological trends for the construction industry

In general, the construction industry does not develop new technological innovations. However, there are potential technological trends which can be used as a strategy to deal the occurring issues in the construction. BouwKennis (2016) investigated which currently developed technologies and innovations are expected to have a huge impact on the construction industry in the upcoming years and which technologies will be the most applied within one year. In Figure 3, the technological innovations with the highest predicted impact over the next five years and the expected application the upcoming year are illustrated. Below (in Table 1) a brief table with explanations of these trends are given.

The innovations shown in Figure 3 and Table 1 can be classified according to the phase in which they are useful: the preparation, realisation or operational phase. Taking the approach of Japan as an example, it can be stated that the technologies developed for the realisation phase, 3D-printing, robots and drones can be the solution to the emerging issues in the construction industry. However, it is important to remark, that most of the above-mentioned trends are interrelated to and dependent on each other. The trends of ABN AMRO (2016) are consistent with the general top 12 trends of AT Kearney, in which the rise of the machines is one of the most important trends at the moment. 'Unmanned systems and robots will reshape businesses' (AT Kearney, n.d.). Together with the development of the Internet of Things (IoT), Big Data and Artificial Intelligence (AI), the developments in robotics are going extremely fast.

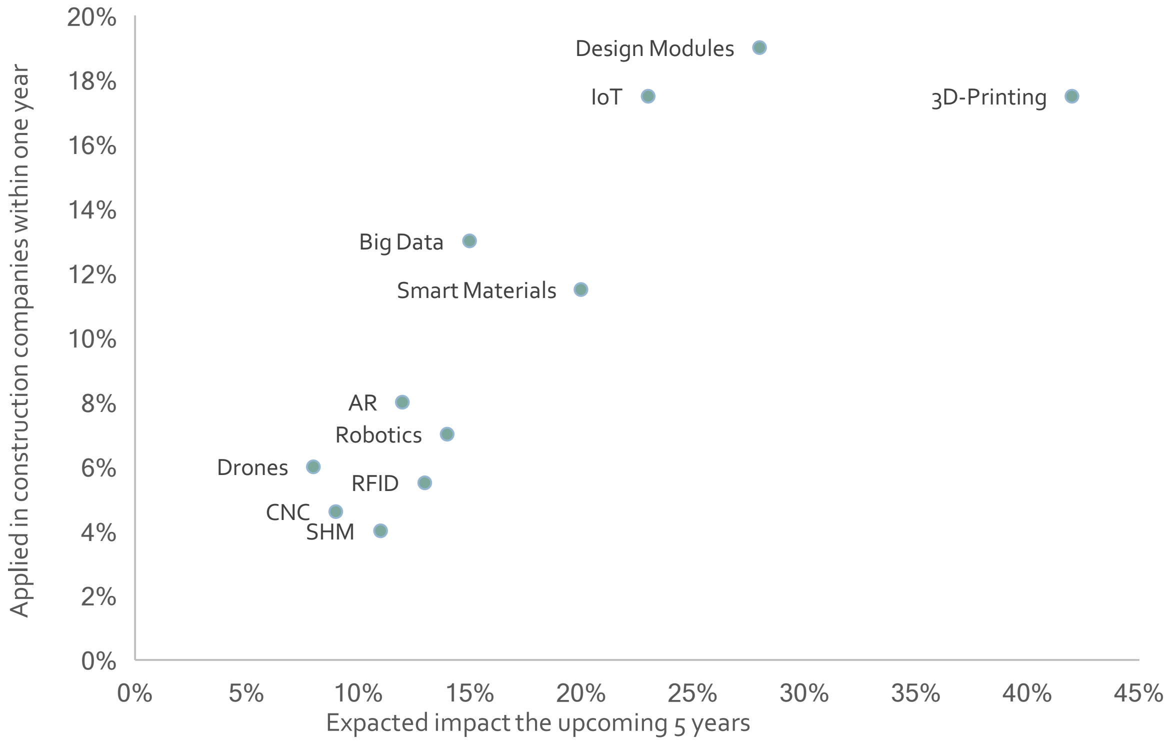


Figure 3 Promising innovations for the construction industry the upcoming years (ABN AMRO, 2016, p. 7)

Technological Innovation	Abbreviation	Description	Phase
Design Modules		Interactive program that allows the end user to design a pre-programmed set of variations.	Preparation
3D-printing		A device that can produce three-dimensional objects based on digital designs by building the object layer by layer.	Realisation
Internet of Things	IoT	An internet development, where objects will be connected to a network and are able to exchange data.	Operational
Big Data		Phenomenon in which large amounts of real-time data from structured and unstructured sources are collected and analysed.	Operational
Smart Materials		Materials that can undergo major changes in their form by external influences such as load, temperature, humidity, acidity (pH), electrical or magnetic fields.	Operational
Augmented Reality	AR	A direct or indirect image of the reality, in which a computer is able to add elements.	Preparation
Robotics		The use of robots for all kinds of functions, from industrial production and self-propelled cars to service-oriented tasks.	Realisation
Drones		Unmanned aircraft.	Realisation
RFID sensors or chips	RFID	A sensor, chip or RFID tag which collects information to read or manage a process.	Operational
CNC-Technology	CNC	Computer-controlled operation tool which makes fast and accurate operations in metal, plastic or wood.	Operational
Self-Healing Materials	SHM	Materials that have the ability to repair damage due to mechanical use.	Operational

Table 1 Brief explanation of trends and innovations (ABN AMRO, 2016, p. 6)

This research will focus on robots, including 3D-printers, as a promising strategy for construction companies to meet the future real estate demands and hold their market position. These technologies are already used in other (manufacturing) industries, but the implementation and usage of robots and 3D-printers in the construction industry stay behind. Although there are some prefab construction factories run by robots, such as Voorbij prefab factory of TBI, on-site robots and 3D-printers are hardly used. Only a few pilot projects have used these new technologies. For example, the 3D printed canal house of Heijmans and DUS architects. To make these new innovations possible for large-scale production, the innovations should be commercialised. This research will investigate how robots at the construction site can become feasible for Dutch construction companies by means of an adjusted business model.

1.2 Problem analysis

Construction companies can use robotisation as a strategy to deal with the emerging issues in the construction market. Taking the automated and robotised manufacturing industry as example, together with the measures Japan undertook to deal with the aging population and following the current technological trends, it can be stated that on-site robots are a solution to deal with the increasing shortage of skilled construction workers, the low productivity and efficiency of the construction industry and the increasing demand for real estate developments. Together with other supportive trends such as the IoT, Big Data and Artificial Intelligence (AI), the developments in robotics are extremely fast. The emerging technology of robotics, might not just be a solution to the above-mentioned problems but offers new opportunities for the construction industry as well.

However, there is one critical point which retards the implementation of robots in the construction industry. According to Halpin and Kangari (1990), innovation becomes possible when there is a need-based feasibility, technical feasibility and economic feasibility. Even though the first two are proven, the latter remains unsearched. The problem lies in the lack of a suitable business model, which can demonstrate the different ways robots can be implemented and the feasibility of this innovation. In one of the papers of Chesbrough, an important corporate innovation world (2010, p. 354), he stated: 'Technology by itself has no single objective value. The economic value of a technology remains latent until it is commercialised in some way via a business model.' In order to make robots possible for large-scale production, the innovation should be commercialised. Although the exploration of new ideas and technologies is mainly not the issue, in general, the ability to innovate the business model through which new technology will commercialise is the main problem (Chesbrough, 2010).

1.2.1 Problem statement

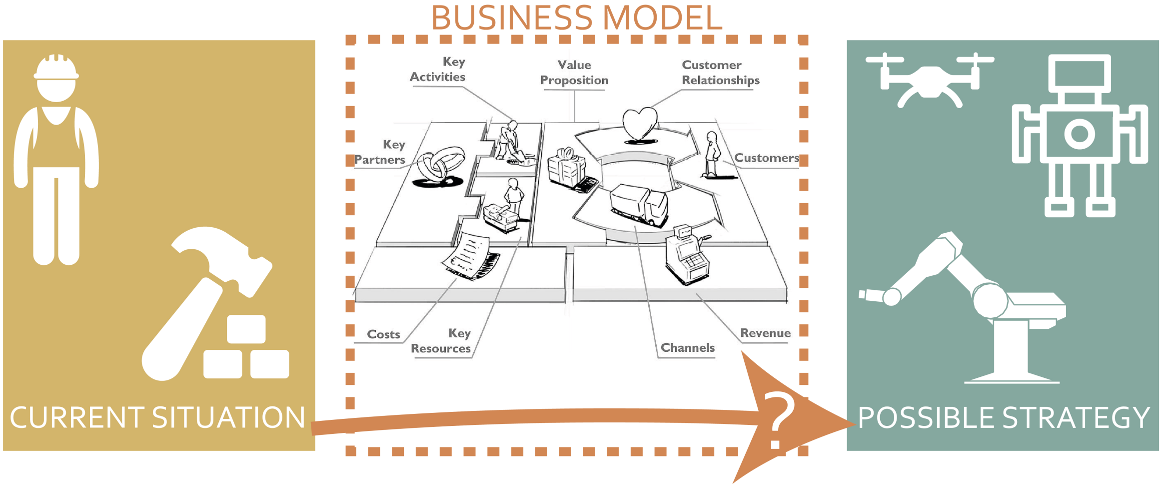


Figure 4 Problem statement (Own image, based on Osterwalder and Pigneur, 2010, p.18-19)

Robotisation can be used as future strategy for construction companies, to deal with the changing construction market. Before on-site robots will be implemented for large-scale production, the economic feasibility must be proven. By means of a business model, the different ways of implementing on-robots as well as the economic feasibility of robots can be demonstrated. However, at this moment a suitable business model is lacking.

1.3 Relevance

1.3.1 Scientific relevance

For a long time, the construction industry was unfamiliar with the R&D of robots, due to the limited available money for R&D in this sector (Abderrahim & Balaguer, 2008). Although in recent years more and more articles have been published about automation and robotisation in the construction industry, no research has been published related to the ability to innovate the business model of construction companies in order to make robots feasible. Although there are several articles written about business model innovation in general, corporate entrepreneurship and even innovation within a construction company, none of the identified articles was related to all subjects: on-site robotics, business model innovation and construction companies. This thesis will focus on all three of the above-mentioned subjects in a way that is complementary to existing research and literature.

1.3.2 Societal relevance

Robots are expected to solve several societal problems in the construction industry. First, the robots can be used in response to shortage of skilled workers, which will increase over the next few years (Gassel, 2010; Peiffer, 2016). Second, the robots can replace human workforce for dangerous or heavy jobs (Halpin & Kangari, 1990). Third, the application of robots will increase the level of productivity and efficiency of robots (Platform Logistiek in de Bouw, 2014; The Chartered Institute of Building, 2016). Solving all these problems will ensure that the future real estate demand will be met. An adjusted business model for construction companies should be designed, to make robots feasible for large-scale production. This thesis will in the first-place investigate how the business models of traditional construction companies should change, in order to make on-site robots possible. the thesis will raise awareness about the relevance of implementing robots in the construction industry.

1.3.3 Utilization potential

Several Dutch construction companies are experimenting with robots and 3D-printers. For example, the construction company Heijmans, together with the start-up MX3D. They are developing a self-printing bridge, which will be located in Amsterdam (Heijmans, n.d.). Heijmans, together with DUS Architects, also experimented with 3D printing techniques to produce elements to construct a canal house. Not only Heijmans but also construction company BAM was experimenting with a 3D-printing project, the landscape house of the Amsterdamse Universe Architects (Landscape House, n.d.). However, both companies are just experimenting with these technologies. This thesis will be helpful for construction companies since it will investigate how the business model of construction companies has to change in order to implement robots for large-scale production.

1.4 Research objectives

This research aims to investigate the way a business model of a Dutch construction company has to change in order to make on-site robots for large-scale production possible. The outcome of this study will be an adjusted business model relevant for large Dutch construction companies. By means of a business model the different ways to implement robotisation as future strategy will be demonstrated. In addition, as part of the business model, the economic feasibility of robots will be calculated.

In addition to the main objective, each part of this research has a sub-objective. These are listed below:

1. To give a comprehensive overview of the state of art of robots for construction.
2. To understand the current business model of large Dutch construction companies.
3. To explore the way another industry has changed its business model due to the implementation of robots.

1.5 Research questions

This research gives answer to the following question:

*'How can **Dutch construction companies** adjust their **business model** in order to make **robots** at the **construction site** possible?'*

In order to answer this main question, the following five sub-questions are answered:

1. What is the state of the art of robots on the construction site?
2. How do Dutch construction companies operate?
3. What does the current business model of large construction companies look like?
4. How did the business model of another industry change due to robotisation?
5. How will individual aspects of the currently used business model of construction companies change due to the use of robots?

1.6 Conceptual model

In Figure 5, the conceptual model is shown to illustrate the relations between the different variables.

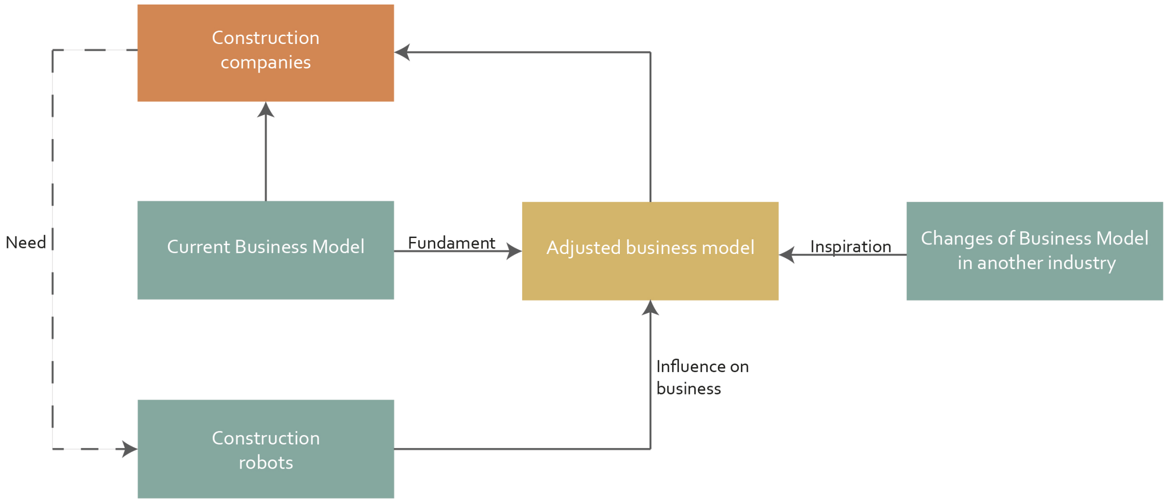


Figure 5 Conceptual model (Own Image)

In the upcoming years, the need for robots in the construction industry will increase, due to the growing shortage of construction workers, the low productivity and efficiency and the emerging competition. Although the technology is already developed, the construction companies cannot implement robots in their current business model. Therefore, an adjusted business model needs to be designed, with as basis the current business model of construction companies, taking in to account the influence of the chosen robot on the construction process. While designing an adjusted business model, changes that had to be made in the business model of another industry due to the implementation of robots will be used as inspiration.

1.7 Research scope

This research consists of three main topics: robots, business models and construction companies. However, these topics are demarcated based on the available graduation time, the relevance of the topics, the available information and the background of the student.

First, the demarcation of robots shall be discussed. In order to find out what kind of construction robots are available, the state of the art is researched, together with the employability of robots. Each kind of robot has a different impact on the business model of construction companies. Therefore, one specific type of robot is chosen and implemented in the business model of construction companies. Since robots for construction are already implemented in factories, this research focuses on the on-site construction robots. More specifically, the chosen robot executes a task in the realisation phase, because this has traditionally been the most important phase of construction companies. Aspects such as technology and legislation are excluded from this research since this research focuses on existing robots, of which the application is already proven.

Second, the demarcation of construction companies shall be explained. This topic is delimited geographically and in size. The location and size of the construction company influence the way it operates. This thesis focuses on large size construction companies in the Netherlands. The reason for this is two-fold: First of all, this research is executed on Dutch ground. Secondly, this research is done for the large size construction company Heijmans. Since Dutch construction companies have multiple businesses and departments, the choice has been made to focus on the residential department. The biggest construction task for the upcoming years is the construction of housing. Since residential projects are in general highly standardised, this might be the most convenient branch to start implementing robots.

Third, the demarcation of business models shall be discussed. The focus of this topic is on the business model of large Dutch construction companies. Currently, the business model of Dutch construction companies has not been researched. Therefore, the business model of several large Dutch construction companies is investigated. In order to proven the economic feasibility, the business models of a row-housing project are compared. one project is compared. The choice for a row-housing project is made, since this kind of dwellings are highly standardised and the information needed to make a calculation is available at the graduation company Heijmans.

1.8 Research Design

In Figure 6, the research design of this thesis is illustrated. This research will have an inductive approach, findings of the literature research, interviews and case study will be used as input to adjust the current business model of construction companies (Bryman, Social Research Methods, 2012). By means of literature research, an overview will be provided of the state of the art of robots for the construction. Besides, the way large Dutch construction companies operate will be explained, and the business model of construction companies will be explained according to the literature. After the literature study, empirical research will be conducted. The currently used business model of construction companies will be investigated and the influence of robotisation in another industry will be explored. The findings of these chapters will be the input for the design of an adjusted business model for construction companies in order to make robots on the construction site possible.

This thesis is sub-divided in several 'how' and 'what' questions. According to Bryman (2008), qualitative research is suitable for answering these kinds of questions. This research strategy creates more flexibility to explore different possibilities.

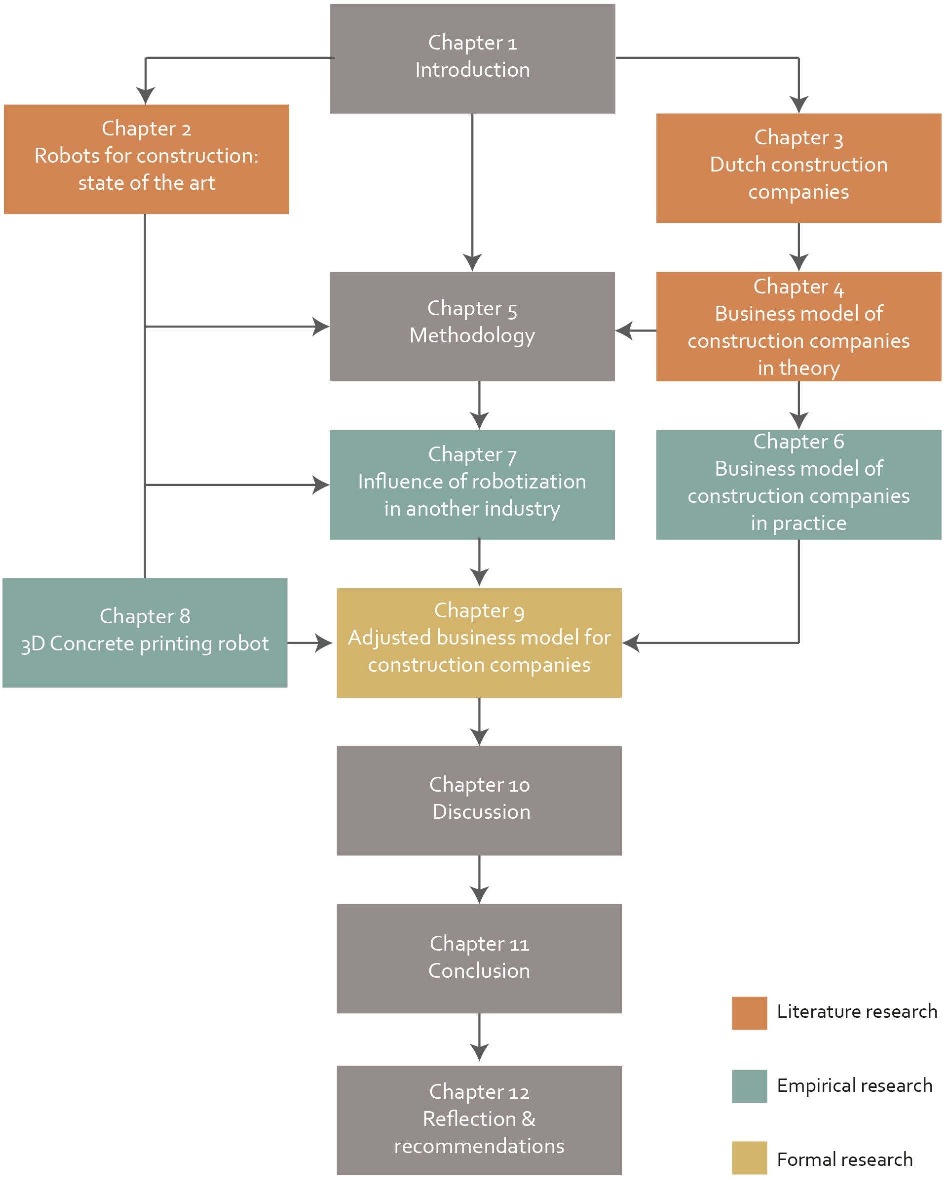
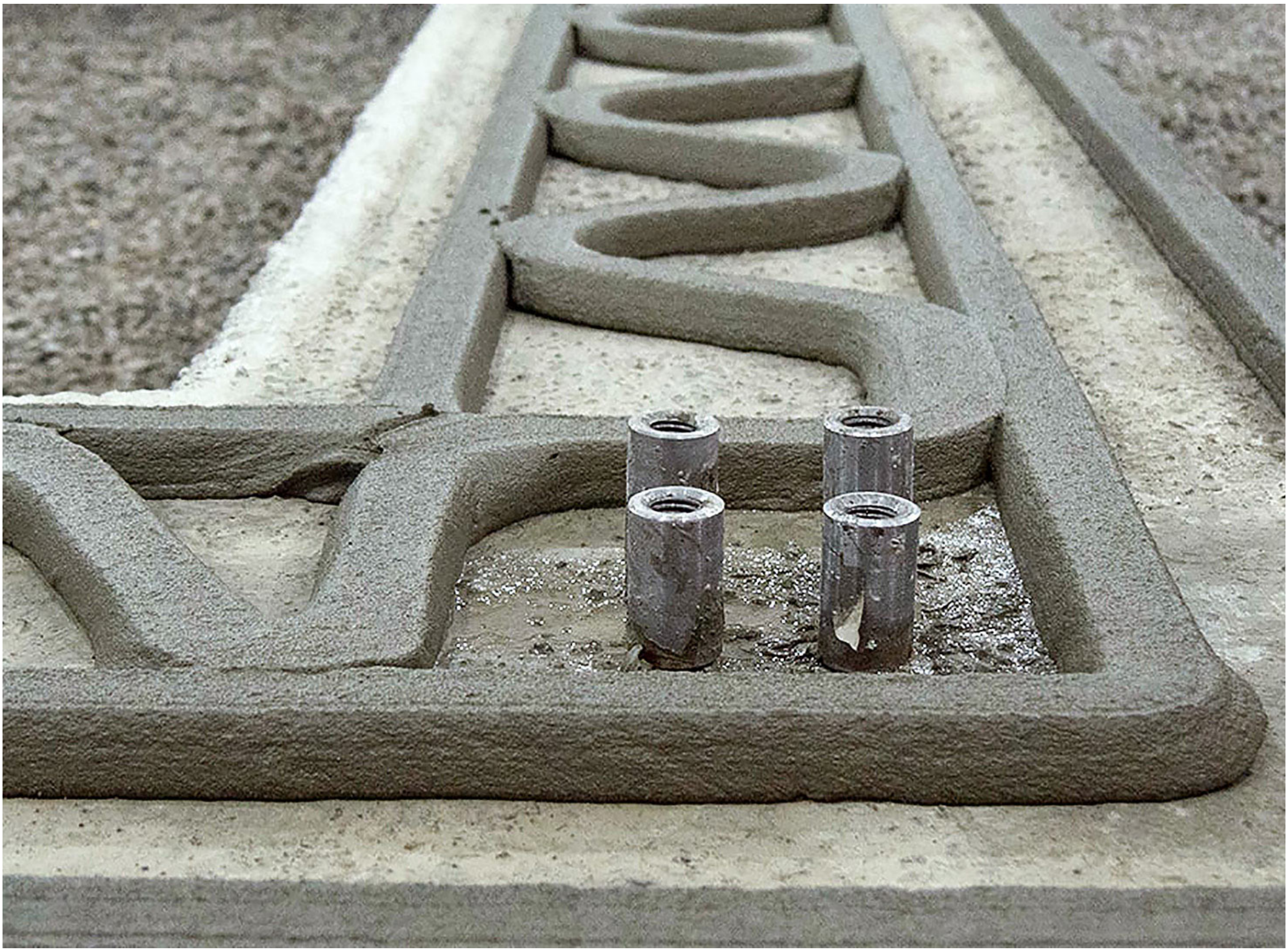


Figure 6 Research design (Own Image)

1.9 Reader's guide

As the final part of the introduction, this reader's guide provides the structure of this report. This research consists of six parts, part A - F, which again are divided into twelve chapters, illustrated in Figure 6. This readers guide is part of the first chapter the introduction, which belongs to part A: The research proposal. Here the motivation, objectives and research questions are described. In part B, a literature overview is provided spread over three different chapters with the following subjects: The state of the art of robots for construction (Chapter 2), Dutch construction companies (Chapter 3) and the Business model of construction companies in theory (Chapter 4). Part C, the methodology, elaborates on the chosen research methods, the selection for a robot and explains the steps to design an adjusted business model (Chapter 6). The empirical research is described in part D, in which first the currently used business model of construction companies is researched (Chapter 6), second the influence of robotisation in another industry is investigated (Chapter 7) and last the chosen robot is described (Chapter 8). All this information is brought together in chapter 9 of part E: Synthesis & Design. In this chapter, the adjusted business model is designed. The last part F: Conclusions, includes the discussion (Chapter 10), conclusions (Chapter 11) and the reflection and recommendation for further research and practice (Chapter 12).



B LITERATURE STUDY

2 ROBOTS FOR CONSTRUCTION: STATE OF THE ART

This chapter gives an overview of the available robots for the construction. Before answering the sub-question, 'What is the state of the art of robots on the construction site?', the term robot is defined and the overall state of the art of robots is given. Besides that, the current employability of robots is set out and the future developments of robots for construction are described. This chapter concludes with an overview of robotised industries.

2.1 Definition of robots

In 1920, the writer of the futuristic play R.U.R, Czech Karel Čapek, used the term 'robot' for the first time to denote a fictional machine. This term was derived from the Czech word 'Robota' which indicates monotonous work, drudgery and servitude (Wikipedia, n.d.). Nowadays the word 'robot' refers to both physical robots and virtual software agents, although the latter is mainly called to the original abbreviation of robot, 'bot'.

The definitions of mechanisation, robotisation and automation all indicate a shift of tasks compared to the traditional situation and are often confused. It is therefore important to formulate the concepts of the above-mentioned terms, before focusing on robots for the construction sector.

The first concept, mechanisation, is the replacement of physical human tasks by a machine. According to Cambridge Dictionary, a machine can be described as: *'A piece of equipment with several moving parts that uses power to do a particular type of work'.* This is the precursor of robotisation, where both physical tasks and rational tasks of humans are replaced by robots. In these definitions, both machines and robots are means to change a process, while automation is a way to manage a process, in which all tasks are executed with technical tools, like robots (Gassel, 1999).

Yet, there is no consensus when a machine can be considered as a robot. Joseph Engelberger, the pioneer of robotics once said: 'I cannot define an industrial robot, but I can tell for sure when I see one (Rehr, 1989, p. 61).' Though among experts, a robot tends to possess at least multiple of the following abilities and functions (Skrorobotics, n.d.):

- Accept electronic programming
- Process data or physical perceptions electronically
- Operate autonomously
- (Partly) able to move
- Operate physical parts of processes of itself
- Interact with their environment
- Demonstrate intelligent behaviour

Also in different dictionaries, the definitions of robots differ. The Oxford Dictionary describes a robot as: *'A machine capable of carrying out a complex series of actions automatically, especially one programmable by a computer.'* While the Cambridge Dictionary concludes that *'a robot is a machine that has to be controlled by a computer in order to perform jobs automatically'.* Although these definitions vary by the inclusion of computer, according to Harris (2002), a computer (or other human controlled device) is one of the components that distinguish a robot from other movable machines. In Table 2 other differences between machines and robots are illustrated.

	Machines	Robots
Operations	One single set	Several jobs and adjustable sequence
Level of movement	Slow and simple movements	Fast and complex movements
Programmed with intelligence	No	Yes
React to outside stimuli	No	Yes

Table 2Differences between machines and robots (Wisegeek, n.d.)

The definitions in van Gassel (1999) and Rouwenhorst (2016) are illustrated in Figure 7. Although the level of intelligence distinguishes a robot from a machine, it is important to mention that a robot with a high level of intelligence is no longer seen as a robot, but artificial life.

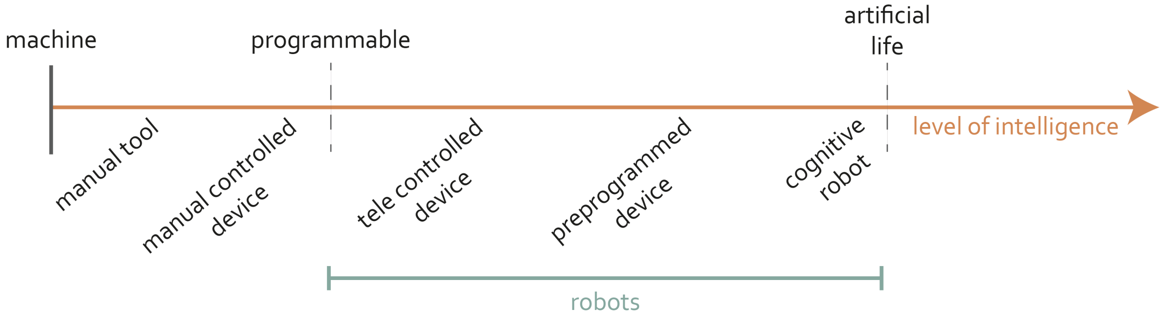


Figure 7 Definition of a robot (Gassel, 1999; Rouwenhorst, 2016)

Subsequently, the following composed definition has been made based on the above-mentioned definitions:

A robot is a smart, multitasking machine, controlled by a computer which is attached to a movable physical body, which (semi) automatically performs jobs and can react to its environment based on given data, calculations and own observations.

2.2 State of the art

The development and employment of industrial robots started in the 70s (Brabantse Ontwikkelings Maatschappij, 2015). Japanese institutions led these developments with the aim to optimise equipment operations, improve safety and to ensure the quality of the built environment. Robots were specially employed in industries which required heavy, rapidly, accurate, reliable and repetitive work, such as the car industry. However, despite the benefits the development and employment stagnated in the 90s, this was due to the economic crisis in Japan and the over-expectations of robotics, while the technology was not developed sufficient enough (Bulusu, 2015). In order to reduce production costs and to deal with the shortage of workers, a solution was found in foreign workers of low-wage countries. Nowadays, the technological capabilities and the renewed focus on production have offered new opportunities for developments of robots (Brabantse Ontwikkelings Maatschappij, 2015).

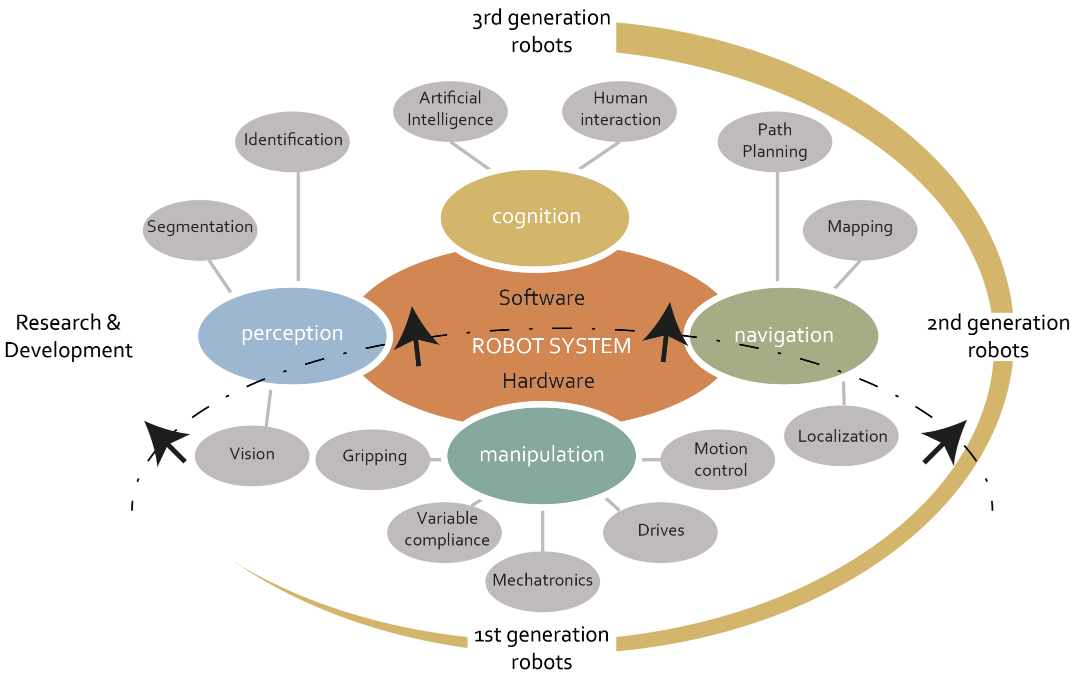


Figure 8 State of the art of the four technological domains (Brabantse Ontwikkelings Maatschappij, 2015, p. 26)

A robot system consists of software and hardware, which can be divided into four technological domains: Manipulation, Navigation, Perception and Cognition. Illustrated in Figure 8.

The first-generation of robots, the classic industrial robots, were mainly focused on the mechatronics, drives and motion control, to improve the manipulation regarding the speed, precision and reliability (hardware). Currently, the second-generation of robots are in development. The focus of the second-generation robots will shift towards perception and navigation (software). In the paragraphs below the state of the art of the second-generation robots will be explained according to the developments in software and hardware (Brabantse Ontwikkelings Maatschappij, 2015).

2.2.1 State of the art of the software

In general, the state of the art of robot software can be described in three points. First, the development of new vision-systems integrated with algorithms. They enable robots to signal and identify objects and humans. Second, with the help of gyroscopes and GPS-systems robots can map their surroundings. This together makes it possible to adjust movements based on the environment, which makes it possible for humans and robots to collaborate in a safe way. Additionally, the rapid development of other navigation and perception technologies creates affordable opportunities for new applications. Third, the contribution of other, not directly related, developments as the increasing computing power of the processor, the formation of open software platforms for Robots and the IoT, enables possibilities to analyse and react to real-time data (Brabantse Ontwikkelings Maatschappij, 2015).

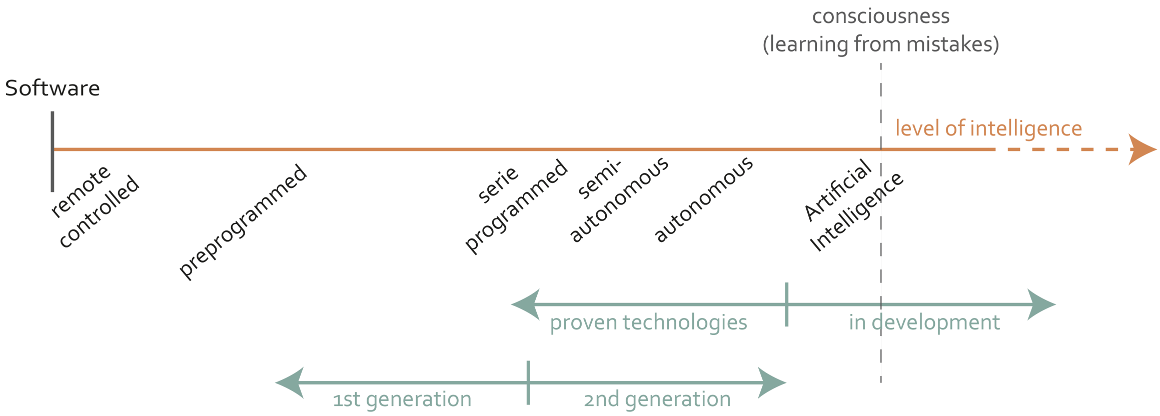


Figure 9 State of the art of intelligence (Rouwenhorst, 2016, p. 40)

For the development of the third-generation robots, the focus will be on the cognition of robots. In Figure 9, the growth of intelligence in the different generations is illustrated. Nowadays there are autonomous robots available. Autonomous robots can perform on their own but cannot react to incoming stimuli (Boscarato, 2015). Although a lot has been written about AI, there is not yet a cognitive robot with an artificial brain with the ability of reasoning, planning and learning (Belloli, 2015; Leroux, et al., 2012).

2.2.2 State of the art of the hardware

The hardware of robots is comprised of five main parts (Hareesha, 2014): Manipulator, End-effector, Actuator, Sensors and Controller/Processor (see Figure 10). These elements are controlled by the software of the robot and can vary based on the specific type of robot.

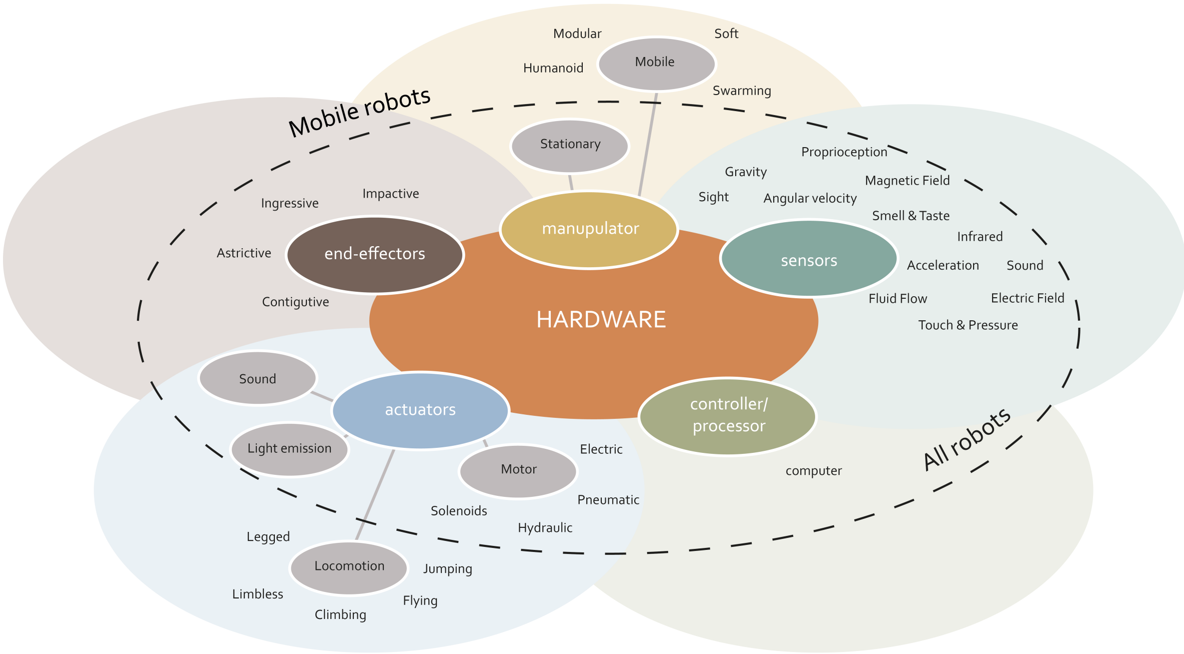


Figure 10 State of the art of hardware (Own image)

The mechanical body of the robots is called the manipulator. Hareesha (2014) divided robots into two categories: stationary and mobile robots. Stationary robots are made for production and are therefore also called industrial robots. They have a fixed base, with a mechanical robot arm which can manipulate the surrounding. Mobile robots have in contrast to stationary robots, a locomotion which makes movements of the whole manipulator possible. Mobile manipulators can be classified according to their morphology. Four categories can roughly be defined: Modular robots, Humanoid robots, Swarming robots and Soft robots. Modular robots are employable for several tasks. Due to the separate parts, different functions can be implemented and parts of the robot can be interchanged (Ijspeert, Crespi, Ryczko, & Cabelguen, 2007; Saranli, Buehler, & Koditschek, 2001; Hatton & Choset, 2010). As the name suggests, humanoid robots are inspired by the human form. Initially, they were developed to improve orthosis and prosthesis (Hirer, Hirose, Haikawa, & Takenaka, 1998; Collins, Wisse, & Ruina, 2001). Swarming is one of the newest fields of developments for robots. This development makes it possible to collaborate between robots. By means of shared data, they are able to react to each other's actions (Şahin, 2005). Finally, the soft robots. These flexible robots are able to move in very limited spaces. They are composed of entirely soft materials and are using pneumatic pressure to move (Trivedi, Rahn, Kier, & Walker, 2008; Shepherd, et al., 2011; Webb, n.d.).

Over the years, the perception of robots has increased, due to newly available sensor technologies. The sensors send their measurements to the controller, which in turn drive the actuators and end-effectors. Currently, the following sensors are developed and applied: acceleration, angular velocity, distance measurements, electric field, fluid flow, gravity, infrared sensing, magnetic field, proprioception, sight, sound, smell and taste, touch and pressure (Pratt, 2003).

The controller or processor is the computer of the robot, the physical body of the software, in which all the information will be integrated. The controller translates the input in output to drive the actuators and end-effectors. The main developments of the controller are focused on the computer power. In order to extend the level of intelligence, the accuracy and perception of robots, a higher power is required.

Actuators include both the motor and the locomotion. The actuator converts the energy of the power supply into movement using a motor. There are four types of engines: Electric, Solenoids, Hydraulic and Pneumatic. Based on the type of the motor and robot, a power supply system is chosen. Stationary robots are mainly plugged in like other machines, while mobile robots require a battery (Harris, 2002). There are several types of locomotion available to enable movements: Legged, Limbless, Climbing, Jumping and Flying locomotion. A legged locomotion can have one, two, four, six or multiple legs. The advantage of legged robots is its ability to move effectively on the uneven environment. Limbless robots can easily pass by terrains, involving topography over a range of length scales. Since this type of robots makes mainly use of wheels, they have difficulty climbing vertically (Hatton & Choset, 2010). However, they can easily move on a variety of surfaces (Marvi, Meyers, Russell, & Hu, 2011). Climbing robots can make use of van der Waals forces (Unver, Uneri, Aydemir, & Sitti, 2006), directional dry adhesives (Heyneman, et al., 2007), or climb like insects with spines (Asbeck, Kim, Cutkosky, Provancher, & Lanzetta, 2006). Fourth, jumping robots are inspired by animals such as kangaroos and hares. The event of jumping is induced by releasing the tension of a spring or due to the combustion of methane and laughing gas (Loepfe, Schumacher, Lustenberger, & Stark, 2015). The last category is the flying robot, mainly known as a drone. Instead of a mobile base, these robots have propellers (Gurdan, et al., 2007). Besides, both a microphone to produce sound and lasers for light emission are seen as an actuator (Pratt, 2003).

The end-effector is the tool on the end of the robot arm or the gripper, which should execute the task. The available grippers can be classified into the following categories: Impactive, ingressive, astrictive and contigutive. Impactive grippers can grasp the object by means of for example jaws or claws. Ingressive tools can penetrate the object, such as needles. Astricive tools are mainly used to lift or shift an object. By means of vacuum, magneto- or electroadhesion the robot will sunction the object. Contigutive tools are used for adhesion by direct contact, such as glue (Monkman, Hesse, Steinmann, & Schunk, 2007).

2.2.3 State of the art of construction robots

Within the construction industry, the use of robots is limited. Only in the IT-related stages, the advent of robots is higher, but the production stages remain rather conservative. Initially, only 3percent of the capital of large construction companies is invested in new technologies. This has to do with the fact that construction companies are not ensured of the return of investment of an uncertain innovation such as 'tomorrow's construction robots'. Also, robot companies are sceptical about developments for the construction industry. Construction companies only consider purchasing proven technologies, which are more convenient to use than their regular construction method. Therefore, robot companies rather focus on civil engineering industry, rather than the house building industry (Bulusu, 2015). Although the implementation of robots is limited, the technology of the second-generation robots is able to carry out heavy, repetitive work in an accurate way also at poorly accessible or dangerous locations (Brabantse Ontwikkelings Maatschappij, 2015). However, the tasks which can be assigned to robots are relatively simple. According to the director of Robomotive, it is not yet possible to program robots for jobs in highly unstructured environments with a variety of tasks (Rouwenhorst, 2016).

2.3 Employability of robots for construction

There are two kinds of tasks robots can execute to improve the construction. First of all, the management and logistic tasks, to support the construction process. Second, the manufacturing tasks. Since this thesis will be focused on the on-site manufacturing robots, the management tasks will be excluded from this chapter.

Robots for construction need to deal with heavy objects, elements with high tolerances, a low level of standardisation, a medium level of prefabrication and industrialisation. Besides this highly unstructured environment, they also should deal with a complex system of actors (Bulusu, 2015). In general, a division can be made into on-site (mobile) and off-site (industrial) robots.

2.3.1 Employability of off-site robots

Nowadays, the increasing use of the prefabricated elements in construction pushed the development of industrial robots forward. Both the production of elements and a part of the assembly is done in the factory. Currently, the employment of robots in factories is mainly focused on producing prefabricated elements, in terms of walls, floors and facades, and in some cases assembling (Bulusu, 2015). Recently, the Dutch Voorbij prefab factory of TBI holding has changed into a robotised factory. A variety of robots are employed to prefabricate walls with a high accuracy and finished with fittings for pipes, electricity and sockets.

Figure 11 Voorbij Prefab Factory in Amsterdam (Heidinga, 2015)

2.3.2 Employability of on-site robots

On-site construction robots are not comparable to industrial robots; they need a huge working area, with a wide ranch, should carry tones and are not doing repetitive work (Balaguer, EU FutureHome Project Results, 2002). In order to stimulate the development of on-site robots, they started robotising machinery (Bulusu, 2015). In the 80s, the Japanese developed multiple types of robots for on-site construction. They created an integrated system with approximately 50 robots. They were programmed to executed specific defined tasks. Both semi and fully automated robots took care of the storage, transport, assembly and construction of buildings. This provided a saving on the labour costs of approximately 50percent. Japan has not offensively offered their construction robots on the world's construction market yet (Bock, 2007). Nowadays more than 200 on-site construction robots have been developed and tested, however only a few of them turned out to meet the requirements and are for sale now. Although the technology of these robots might be proven, the application of these robots caused problems or at least financial drawbacks. Although robots on the construction site in the Netherlands are hardly applied, in literature, multiple tasks of on-site construction robots are described. The possible tasks of these on-site robots, found in literature, are summarized in the table below.

Construction tasks
Assembly
Building skeleton erection
Coating of fire protection on steel
Concrete distribution
Earthwork
Interior finishing (painting, plastering, tiling)
Lifting heavy elements
Masonry
Removal of old coating
Road paving
Surface finishing (concrete, tile-setting)
Welding
Window glass mounting

Table 3 Construction tasks of on-site robots (Bock, 2007; Bulusu, 2015; Elattar, 2008; Abderrahim & Balaguer, 2008; Liu, 2017)

This table corresponds with the research done by Liu (2017), who recently graduated from the Delft University of Technology on the topic of Construction Robotics. For his research, he systematically reviewed all the articles written for the International Symposium on Automation and Robotics of Construction (ISARC) since 2012.

2.4 Advantages of robots

The power of robots instead of human workers has several advantages for the construction industry. In this paragraph, six advantages of robots are explained.

First, the construction industry is labour intensive, which means that the construction industry is dependent on skilled workers. However, over the years a shortage has occurred. Robots will ensure that the production capacity will remain when labour is unobtainable (Peiffer, 2016). Second, robots will improve the productivity and efficiency of the construction industry. This will not only increase the production capability of construction companies but will also reduce the costs since the labour costs take a large part of the total costs of a construction project (Elattar, 2008; Kangari, 1985). The third advantage is the improvement of the safety and health conditions of construction workers. Each year, thousands of construction workers are injured or even killed due to their work. Studies have shown that especially on-site a lot of accidents occur (Bulusu, 2015). Abderrahim & Balaguer (2008), Elattar (2008), Rhaman, Khan, & Shakil (2016) and Kangari (1985) all issued that working in the traditional construction environment is labour-intensive and is associated with multiple risks. Carrying heavy objects, working on scaffolds and working with numerous uncoordinated actors increases these risks. By making use of robots some of these risks and safety issues can be diminished, by deploying machines for dangerous jobs (Elattar, 2008).The fourth advantage is the improvement of quality and accuracy by using robots. Due to the inconsistent human interpretation, the high number of different workers which are involved in the project and the complexity of the project, the accuracy and quality differ per worker (Elattar, 2008; Kangari, 1985; Yagi, 2006). According to ABN AMRO (2016), robots will improve the accuracy. Robots work in mm precision, and therefore construction defect will decrease. Currently, the construction of housing is a mass production. With the advent of robots, a shift can be made to mass customisation, in which adaptation and variation in the housing sector become possible. Robots can manufacture based on a BIM-model, therefore differentiation is no longer more expensive (Brabantse Ontwikkelings Maatschappij, 2015; Pedersen, et al., 2016). Last, the sustainability advantages of robots. Nowadays a lot of waste is produced during the construction and demolition of buildings. By making use of robots, an oversupply of, for example, concrete can be prevented due to the accurate calculations and measurements. Moreover, it might be possible to program the robots in a way that they can inverse manufacture the buildings in a way that the materials can be easily reused (Yaginepppie, 2006).

2.5 Critical points

The advent of robots will bring several advantages. However, there are also some public concerns with regard to robots. Although all of these points should be taken into account, they do not apply to all the new technologies in the field of robots and their impact on the implementation of robots is questionable.

First, there are concerns about increasing unemployment when robots take over. According to Bruegel 49,5 percent of the jobs in the Netherlands will vanish due to the advent of robots (Bowles, 2014). ABN AMRO (2016) is predicting a shift, in which low educated functions will be taken over by high educated employees. However, at this moment there is a shortage of high skilled workers in construction. Rhaman, Khan & Shakil (2016) reassure that the increment of production by robots creates new jobs in the manufacturing and supplier-customer chain field. Second, since robots are dependent on electricity, new problems of failures may occur. Also, the amount of needed electricity will change due to robotisation. Third, the liability of failures made by the robot on site is not established yet. Fourth, the lack of legislation for on-site robots or building requirements to start building with robots may delay the building process.

2.6 Robotisation in other industries

The robotisation in the construction industry in growing. However, there are several other industries far ahead with robotisation. The manufacturing industry, such as the automotive is number one supplier of industrial robots, see Figure 12. Technologies developed for these industries are also introduced in the construction industry (Jørgensen & Emmitt, 2008), since the executive tasks are rather similar. However, this only applies to off-site robotics, since these are rather industrial and thus stationary factory robots.

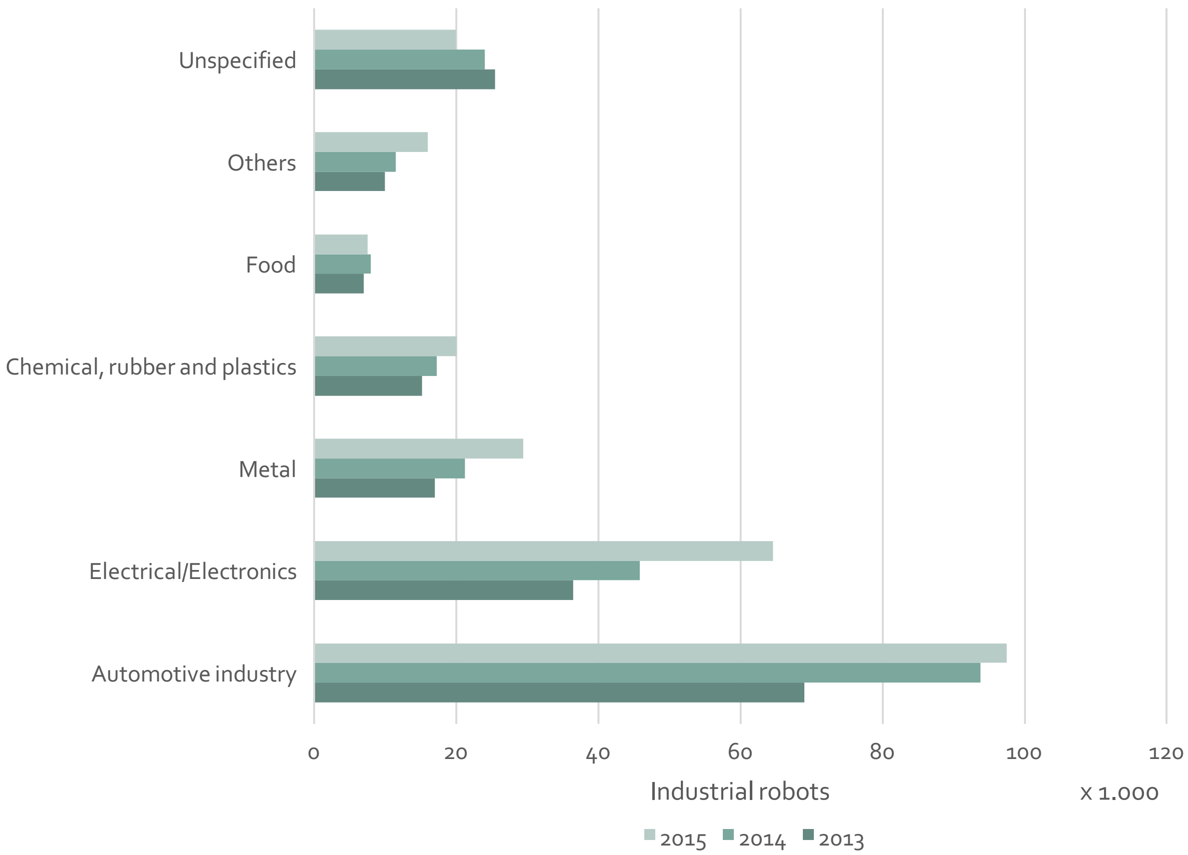


Figure 12 Estimated worldwide annual supply of industrial robots (International Federation of Robotics, 2016, p. 14)

According to the statistics of the service robots, which are mainly mobile robots, they are mostly applied for logistic tasks, followed by military uses, see Figure 13. In contrast with the industrial robot arms, there is a wide range of different kind of service robots available. For the logistics and defence, these are mainly AVGs and drones. While for the field tasks 90 percent of the robots are milking robots, of which Dutch robot producer Lely dominates the sector (Brabantse Ontwikkelings Maatschappij, 2015). Also, mobile barn cleaners and agricultural robots are used for field tasks. In the upcoming years, an enormous growth of robotisation in the farming and livestock breeding is expected. The medical sector has only 3 percent share of the total sales of robots. The most important robots for the medical sector are the robots which can assist surgeries and therapies (International Federation of Robotics, 2016).

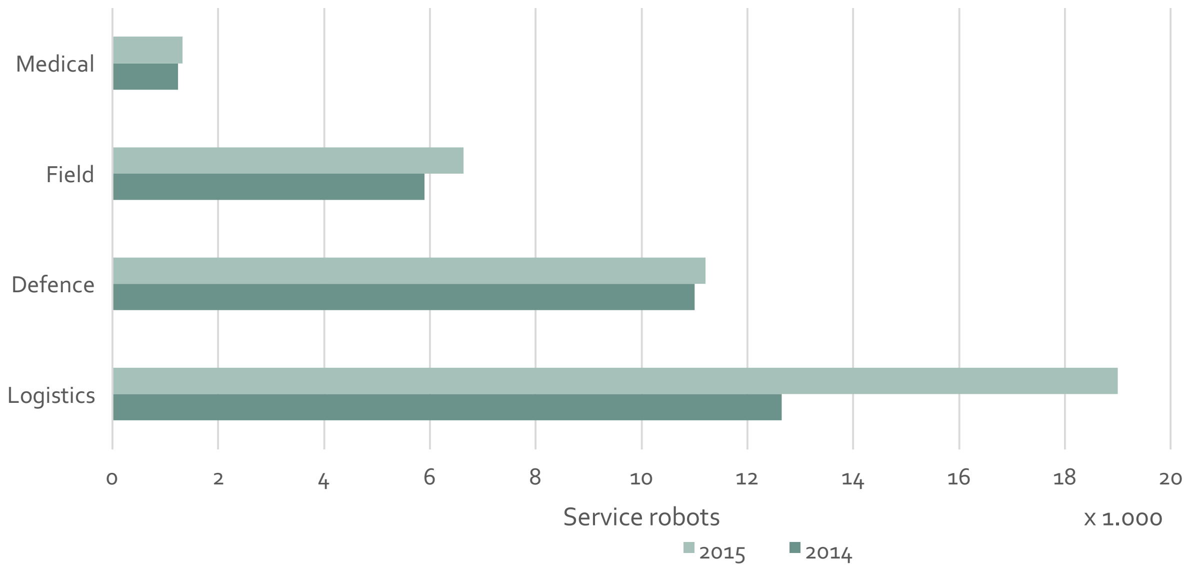


Figure 13 Estimated worldwide annual supply of service robot (International Federation of Robotics, 2016, p. 4)

2.7 Conclusion

In this chapter, the following sub-question is answered: 'What is the state of the art of robots on the construction site?'

The state of the art of robots can be explained according to the software and hardware developments. Currently, second-phase robots are on the market, these robots are able to execute simple but heavy tasks in an accurate way. In comparison with the first-generation robots, their intelligence has increased to an autonomous level. In addition, the perception and navigation are improved by means of vision-systems, GPS and gyroscopes (Brabantse Ontwikkelings Maatschappij, 2015). The hardware developments can be explained according to the five elements of a robot: the manipulator, sensors, controller, actuators and end-effectors (Hareesha, 2014). In order to make new applications of robots possible the computer power has increased. (Brabantse Ontwikkelings Maatschappij, 2015). The combination of multiple tasks and a highly unstructured environment such as the construction site are not yet programmable (Rouwenhorst, 2016).

Robots for the construction can be divided into on-site and off-site robots. Off-site robots are already widely used in the prefabrication of housing. Within these robotised factories, prefabricated elements of dwellings are produced in a highly accurate way (Bulusu, 2015). The implementation of on-site robots is minimal. According to literature fifteen tasks can be executed on the construction site (Bock, 2007; Bulusu, 2015; Elattar, 2008; Liu, 2017): Assembly, building skeleton erection, coating of fire protection on steel, concrete compaction, concrete distribution, earthwork, indoor plastering, interior finishing (painting, plastering, tiling), lifting heavy elements, masonry, removal of old coating, road paving, surface finishing (concrete, tile-setting), welding, window glass mounting.

In the future, robots are expected to:

1. Solve the shortage of workers (Peiffer, 2016).
2. Improve the productivity and efficiency in the construction (Elattar, 2008; Kangari, 1985).
3. Increase safety and health conditions of construction workers (Bulusu, 2015; Abderrahim & Balaguer, 2008; Elattar, 2008; Rhaman, Khan, & Shakil, 2016; Kangari, 1985).
4. Improve the quality and accuracy of buildings (Elattar, 2008; Kangari, 1985; Yagi, 2006; ABN AMRO, 2016).
5. Ensure a shift from mass production to mass customization (Brabantse Ontwikkelings Maatschappij, 2015; Pedersen, et al., 2016)
6. Improve the sustainability of the construction industry (Yagi, 2006).

3 DUTCH CONSTRUCTION COMPANIES

In this chapter, a concise overview is given of the overall construction industry in the Netherlands. The various fields in which they operate are given and the ten largest construction companies are listed. Furthermore, the changing role of construction companies is explained, and the different used construction methods for row-houses are given. Together this provides the input to answering the sub-question of this chapter: 'How do Dutch construction companies operate?'

3.1 Heterogeneity of construction companies

The Dutch construction industry is highly fragmented and consists of 156.000 companies, which are active in the field of civil, infrastructure or real estate construction. The majority of these companies, almost 80 percent, are sole proprietorships. In the last decade, a concentration has taken place. Approximately 500 small construction companies became part of one of the 12 largest construction companies (Wikipedia, n.d.; Loosen, 2002). The top 10 construction companies with the highest the revenue is illustrated in Table 4. The remaining firms are small to middle size companies. Only 315 Dutch construction companies have a human capacity of more than 100 employees (Bouwen Nederland, 2017; Hompes & Rijt, 2010).

Construction companies	Revenue 2016 (x million euros)	Operating field
BAM	7423	Infra, RE, Residential
Volker Wessels	4906	Infra, RE, Residential, Installations
Boskalis	3240	Infra, Civil, Offshore, Maritime
Van Oord	2579	Civil, Offshore
Heijmans	1979	Infra, Civil, RE, Residential, Utility
Strukton	1907	Infra, Civil, RE, Installations
TBI	1557	Infra, Residential, Utility, Technique
Dura Vermeer	1052	Infra, RE, Residential, Utility
Ballast Nedam	850	Infra, RE, Residential, Utility
Van Wijnen	693	RE, Residential, Utility
Total	26186	

Table 4 Top 10 construction companies of 2015 (Cobouw, 2016)

While the smallest construction companies are in general focused on one of the construction fields, the largest companies operate in multiple disciplines (Cobouw, 2016). However, the different disciplines in construction companies are separated by independent entities (Loosen, 2002).

Moreover, when focusing on the residential sector, only seven of the largest construction companies operate in this field. These companies focus on apartment buildings, row houses, semi-attached dwellings or detached housing. Within these housing types, row houses are the highest standardised dwellings. The distribution of housing types differs per company.

3.2 Changing role of construction companies

Over the years, the role of large construction companies has changed. Initially, construction companies were involved in the realisation phase of a construction project, in which they were responsible for several construction tasks such as the construction of the foundations, placing walls and floors and the masonry of the dwelling (Dorée & van der Veen, 1999).

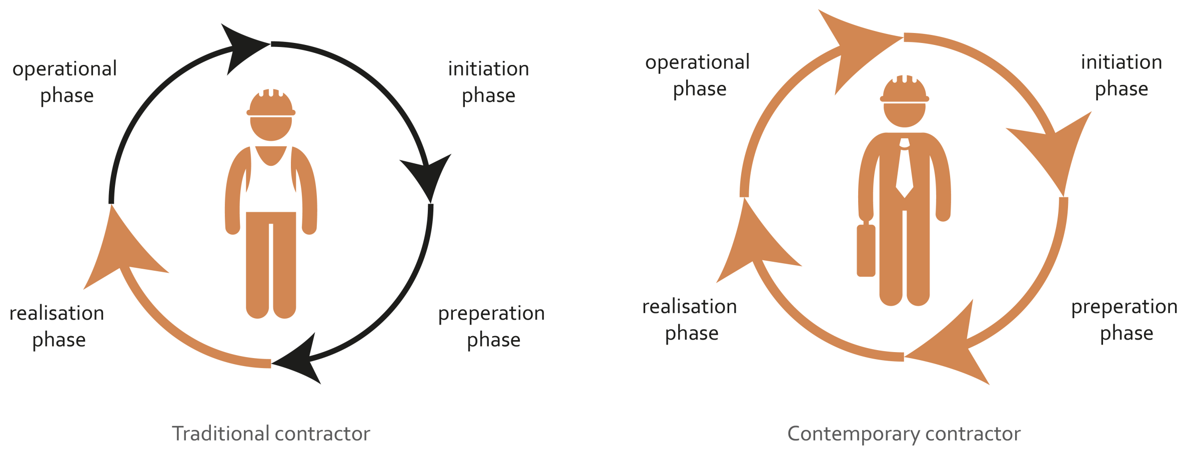


Figure 14 Changing role of construction companies (Own image)

In 1999, Doreé & van der Veen (1999) already spoke about the change of construction companies that became apparent. The contractor, as a traditional supplier of execution capacities, started expanding their business with complementary services, such as financing, engineering, maintenance and exploitation, illustrated in Figure 14. Due to the demand of the market for the lowest-bid, construction companies aimed to increase the flexibility and efficiency of their organisation. This resulted in the rejection of both equipment and human workforce. Nowadays construction companies are outsourcing several tasks to smaller sub-contractors. The construction companies shifted from executive party to management and network organisation; a coordinator of manpower, equipment and products of sub-contractors (Dorée & van der Veen, 1999; Loosen, 2002). This shift is supported by the demand of the clients, to have one party which is responsible for the whole process (Dorée & van der Veen, 1999).

Moreover, the large construction companies in the Netherlands are also contemporary developers. Traditionally seen, developers and construction companies differ, especially on the ground of management, creativity, risk management, market knowledge and collaboration capabilities (Makkinga, Voordijk, Reymen, & Dieren, 2006; Bleyser, 2002). However, construction companies have gained more ground in the construction process. Forward integration created an opportunity for construction companies to develop in addition to their initial job. This increased the integration of design and construction. In contrast to other developing companies, construction companies are only developing to preserve their production consistency. Although the terms such as developing contractor (Dutch: Ontwikkelende bouwer) and building developer (Dutch: Bouwende ontwikkelaar) are commonly used for the largest construction companies, the building and developing departments are independent entities within the construction companies (Loosen, 2002). In addition, the expansion of the scope of construction companies, is supported by the requirements of the client to have one responsible party for their project, and the land position which the largest construction companies possess (Loosen, 2002).

In contrast to the large companies, the small construction companies persist to their original core business. They are still executive contractors, which execute the construction projects of other developers, individual clients or are employed as sub-contractors of larger firms (Loosen, 2002).

3.3 Construction methods

There are five construction methods used for the construction of row houses in the Netherlands (Bongers, 2007). In this paragraph, the five methods will be elaborated. However, in practice mainly four of these methods are used by large Dutch construction companies: casting, masonry, prefab elements and prefab units.

	Casting	Masonry	Wooden skeleton	Prefab elements	Prefab units
Preparation time	Medium	Short	Long	Long	Long
Construction site	Big	Medium	Small	Small	Small
Construction time	Medium	Long	Short	Super Short	Super short
Consumer-oriented	Low	High	Low	Medium	Medium
Equipment cost	Super high	Low	Low	High	High
Finishing	High	Low	Low	High	Super high
Labour intensity	Low	Super High	Medium	Low	Very low
Scale of the project	Big	Small, variation	Small	Big	Big
Weather dependency	Super high	Medium	Low	Low	Low

Table 5 Construction methods for row houses (Own table, based on Bongers, 2007)

The method applied to a specific project depends amongst others on the size of the project, the number of replications, the variety within the project, the design of the architect, the size of the building site, the in-house knowledge, the available equipment and the budget, see Table 5.

3.3.1 Casting method

The casting method produces a type of dwellings of which both floors and walls are poured in concrete, by making use of a formwork. This creates a monolithic building that does not require additional stability. For casting, a tunnel is needed, which is highly expensive to rent. As a result, of the standard size of the tunnel, standardized houses will be produced. Casting is only suitable for large-scale projects, as the tunnel is expensive. Casting is a fast way to build. However, this method is highly dependent on the weather, because of the wet concrete. Since each house is a replica of the former, the property cannot be adapted to the specific requirements of the customer. In addition to the expensive equipment that is required, the craftsmen who can cast, are scarce (Bongers, 2007).

3.3.2 Masonry method

For the masonry method, bricks, blocks or non-storey high elements are glued or built as masonry construction. These can be bricks, concrete blocks, concrete bricks or lime sandstones; the latter is the most used in Dutch construction. Usually, the masonry building is constructed with system floors, such as a wide-plate floor. As this is not a monolithic construction, an extra stability wall is required. Masonry is perfect for small-scale projects or projects with a wide variety since no formwork is required. For equipment, only scaffolds are needed which makes it an ideal construction method for small construction sites. Since all the pipes will be cut in the wall when the construction is completed, this house can be perfectly adapted to the wishes of the consumer. In addition, this construction method requires a short preparation time. On the other hand, there is a high labour intensity on the construction site. Also masonry craftsmen become scarce (Bongers, 2007).

3.3.3 Assembly of wooden skeleton method

The assembly method of a wood skeleton is a kind of prefabrication method. Wooden styles and rules are prefabricated in the factory and only need to be assembled. Often the ground floor is built with a concrete floor. Construction struts and wall panels ensure the stability of the house. The advantage of this construction method is that it is easy to combine with other building methods. Because all parts are already tailored, the on-site building can be done fast. In addition, the own weight of the construction is very light therefore little equipment is required, which positively influences General Construction Cost. This method is also suitable for small construction sites. Due to the fact that the construction will be assembled with dry materials, it can be built under all weather conditions. Disadvantages of the wooden skeleton are mainly the standard dimensions which make it impossible for consumers to adjust the dwelling according to their wishes. Additionally, houses raised in wood are experienced as unpleasant, it is sound-sensitive. You can literately hear every step you take. Since all parts are delivered ready and ready, it takes a long preparation time. This construction method is nowadays hardly used by large construction companies (Bongers, 2007).

3.3.4 Prefabricated elements methods

Prefabrication is gaining popularity among Dutch construction companies. In prefabricated houses, all the elements, such as floors, inner and outer walls are produced in the factory in a conditioned environment. This ensures a high-quality building. The prefabricated elements only need to be assembled on the construction site. Although the on-site construction time is minimal, this method requires a long preparation time in the factory. As pipes and shafts are already prepared in the factory, consumers can only influence the project in the initial phase. However, prefabrication requires heavy equipment, such as a crane to get the heavy concrete elements in place. Since all the walls are already smooth, almost none finishing operations are needed. In addition, this method is perfect for small construction sites, because the elements will be delivered just in time. This method is often used for large-scale projects (Bongers, 2007).

3.3.5 Prefab unit method

The prefab unit construction method is quite similar to the prefabricated element method. In this case, even less time is required on the construction site because all the ready-made units arrive at the building site, which only has to be pushed together. Often the units are finished in detail, so that finishing work is no longer necessary. Due to the large elements, large cranes are needed, and the transport costs will be higher than with the prefabricated elements method. This is the fastest construction method (Bongers, 2007).

3.4 Conclusion

In this chapter, an answer is given to the question 'How do Dutch construction companies operate?'.

The Dutch construction industry consists of 156.000 companies operating in the fields of civil engineering, infrastructure, real estate construction (Hompes & Rijt, 2010; Bouwen Nederland, 2017; Wikipedia, n.d.). While the small construction companies are mainly focused on one of the disciplines, the largest companies operate in multiple fields. However, each department is, in general, an own independent entity within a construction company. In the residential sector, different kind of housing is constructed of which row-housing is the most standardized product.

Traditionally, large construction companies were only involved in the realisation phase, where they were responsible for the construction itself. However, their role shifted from contractor to more a management-oriented company. Instead of having all the carpenters in-house, they started hiring several specialized sub-contractors, in order to become flexible and increase the efficiency. Furthermore, forward integration made it possible for construction companies to take care of the development of their own construction project. However, they only developed to ensure their own construction consistency (Dorée & van der Veen, 1999). This is in contrast with small or medium-size companies which are in general only focused on the construction itself and have still carpenters in-house (Loosen, 2002).

For the construction of row-houses different methods are used (Bongers, 2007): Casting, Masonry, Assembly of the wooden skeleton, Prefab Elements and Prefab units. Currently, wooden skeletons are hardly used for housing projects within the Netherlands. The choice of a specific method is based on the design of the project, the location, the number of replications and the budget of the project, the in-house knowledge of the construction companies and the available equipment. Besides, the construction method has not only influence on the construction time, the cost of the project, but also on the flexibility and adaptability of the design and the number of actors involved (Bongers, 2007).

4 BUSINESS MODEL OF CONSTRUCTION COMPANIES IN THEORY

This chapter elaborates on business models of construction companies. First, the definition of the term business model is disclosed. Second, business model innovation is explained, followed by an investigation of business models of construction companies. The last part of this chapter provides a business model framework, completed for construction companies. This chapter answers the third sub-question based on literature: 'What does the current business model of construction companies look like?'

4.1 Definition of business model

In 1975, the concept of business models was introduced. With the advent of internet technologies in the nineties, managers had to rethink their initial business logic. Business models can be recognized in the business history, but due to the fast increase of business model innovations in the entire society, they have attracted the attention of practitioners (Osterwalder & Pigneur, 2010). This has led to increasing hits on google; starting with 600 hits in 2000 they increased to 102 million in 2010 (Bouwman, et al., 2012).

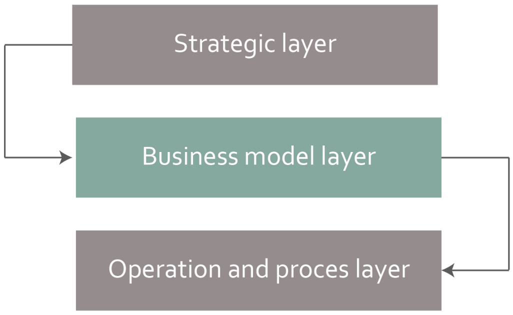


Figure 15 Positioning of a business model (Pekuri, 2015, p. 36)

In 1987 Andrews (1987) stated that the function of a business model is a modern variation on the classic definition of 'the strategy of a business unit'. This includes a value proposition, market segment, value chain, cost structure, profit potential, value network and competitive strategy. Currently, the emphasis of business models shifted from competition to the customer value creation (Rosenbloom & Chesbrough, 2002). Although no accepted definition of the term business model has emerged, there is a clear distinction between a business strategy, business model, business case and an earnings model (Morris, Schindehutte, & Allen, 2005). A business strategy is the future plan of the business in order to capture value. It describes how the company will engage with competitors and how the company should respond to the actual market environment. The business model is the link between the strategy and the operations, as illustrated in Figure 15. It shows how a company is structured and how it makes money and to whom it sells its products. A business model can be used for the entire company, a business level within an organisation or just for one specific product. In a business case, one single product or alternative of a company is demonstrated, to see if there is potential and if it will generate cash flow. The latter is sometimes confused with the earnings model, which also proves the economic feasibility, but on scale of a specific department or the entire company, instead of a particular alternative or product (Schmidt, 2017).

In this thesis, the definition of Osterwalder and Pigneur (2010, p. 14) is used: '*A business model describes the rationale of how an organisation creates, delivers, and captures value'*.

Figure 16 Business Model of Rosenbloom and Chesbrough (Rosenbloom & Chesbrough, 2002, p. 536)

Every organisation has either an explicit or an implicit business model, in which they explicate how they do or would like to capture the value of their business activities. Depending on the sector and the specific company, different types of business models can be applied. An example design of a business model is shown in Figure 16. Although there is no consensus about the definition of a business model and neither about the primary components, most of the d descriptions include value creation and value capturing as functions of the business model. In addition, most frameworks also include resources, activities or value networks in order to create value (Rosenbloom & Chesbrough, 2002).

Although a business model is meant to explain how a company creates and captures value, it is also a tool for managers to visualise, discuss and communicate the vision of the company and a tool to align employees and stakeholders (Pekuri, 2015).

4.2 Business model innovation

Nowadays, more and more technologies are developed at high speed. In order to remain in the same market position, companies should constantly innovate. The key to unlocking the value of new technologies is to commercialise them in a suitable business model (Rosenbloom & Chesbrough, 2002). Although not all innovations within an existing company require a new or adapted business model, some innovations do not employ the existing business model, and thus a new one should be designed to capture the value of the technology. A business model will ensure that this new technological innovation will be employed in an economically feasible way. In case, a technology is not included in the business model, the innovation might not capture the (financial) value it is able to produce (Rosenbloom & Chesbrough, 2002).Two types of innovation can be divided, process innovation in which the process to produce a product is improved or product innovation, in which the final product or service is changed by means of new available technologies. In addition, an innovation might not just have financial consequences; it can influence all the separate elements of an existing business model (Mokhlesian & Holmén, 2012). Furthermore, a business model can also be the subject of innovation itself (Zott, Amit, & Massa, 2011). This is the case for example when the process, the value proposition or revenue models are changed (Pekuri, 2015).

Although the innovation of a business model increases the chance that a company remains in its market position, a high degree of risk is involved. It requires an insight in both technology and market demand, therefore identifying and executing business models is an entrepreneurial act (Rosenbloom & Chesbrough, 2002).

4.3 Business models of construction companies in theory

So far, limited research has been done on the general business model of construction companies. Only one research is found, relating to both subjects: business models and construction companies. Pekuri (2015) has done several studies on the role of business models of construction companies in Finland. Currently, the development of business models within the construction industry is still at an early stage (Brady, Davies, & Gann, 2005), but understanding a business model, the content and potential, provides a starting point for managers in the construction industry to exploit the possibilities of innovations (Pekuri, 2015).

The construction industry can be classified as a heterogenic project-based business. This means that multiple projects run simultaneously or sequentially, in order to achieve the business goals (Artto, Martinsuo, & Kujala, 2011). Project-based businesses are different from others, because the projects are mainly one of a kind, are limited by time and involve hostile relationships within the complex supply chain (Mokhlesian & Holmén, 2012). The construction projects are not just executed by the construction company itself, a large part of this activities is performed by sub-contractors such as manufacturers and suppliers of construction materials, architects, designers, consultants and external carpenters (Segerstedt & Olofsson, 2010; Dubois & Gadde, 2000; Pekuri, 2015). Amongst others, the large supply chain causes a high risk, reactive and slowly changing business (Bourdeau, 1999; Kibert, Sendzimir, & Guy, 2000). In addition, this is also the reason of a low innovation level in this sector, which is comparable to the service sector rather than the manufacturing industry (Brochner, 2010). The innovation, which is employed in the construction industry is developed by other supply partners. This kind of innovation is called outside-innovation (Osterwalder & Pigneur, 2010). Moreover, there is no consensus about the level on which the business model applies, whether this is tailored for each specific project, or if it is fixed for the whole project level (Pekuri, 2015).

In the research of Pekuri (2015) the definition and the purpose of a business model of construction companies are investigated by conducting interviews with managers in practice. First of all, he concluded that in general managers believe to know what a business model is and how their business model is functioning. However, within companies, different definitions and explanations are given by managers, which are not corresponding with each other neither with the definitions given in other industries or academia. According to the managers, business models include elements such as: 'the field of operation, business segments, modus operandi, certain project delivery modes and contract types' (Pekuri, 2015, p. 51). Höök and Stehn (2014) support these findings. According to them, the unawareness of business models in the construction reduces management effectiveness and hinders performance.

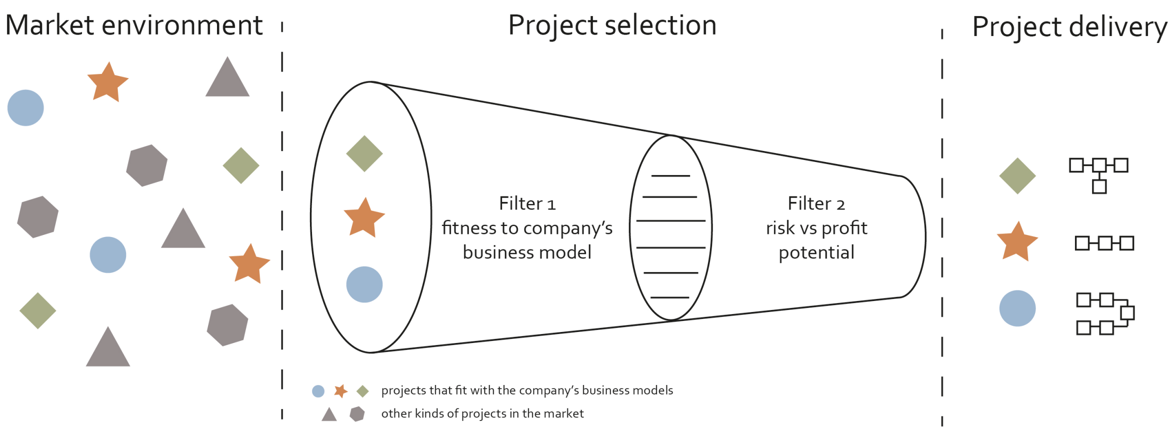


Figure 17 Framework for project selection that is guided by business models (Pekuri, 2015, p. 54)

Furthermore, the purpose of a business model is researched. According to literature, a business model pretends to evaluate whether a project suits the company or not. By ensuring the suitability of the project, the chance of executing a project successfully will increase (Pekuri, 2015). In this sense, a business model can be used as filter, before making a risk/profit analysis. However, the results of the held interviews have shown that the majority of the construction companies do not use the business model to restrict or guide the company in such a manner. Conversely, they are flexible in the kinds of projects they are willing to do. According to the findings of Pekuri (2015), decision making within the construction industry is mainly based on the size of the company, instead of the business model. 'Larger companies have the financial resources to engage in more valuable projects, while smaller firms do not have to carry the back-office costs of large companies and thus they are more competitive in smaller projects' (Pekuri, 2015, p. 52). Nevertheless, both large and small size companies assess the level of risk associated with the project and determine the profitability/return on investment of such a project. Therefore, it can be stated that the business models of construction companies revolve around internal efficiency, instead of customer value creation (Pekuri, 2015). Since the construction industry is project-based, they are mainly focusing on ensuring the stream of projects to provide a cash flow, then selecting the right project according to their business model. The construction industry is seen as the 'anything to anyone' business (Pekuri, 2015). A traditional business model for 'anything to anyone' businesses, such as construction is shown in Table 6. In addition, the interviewees use the business model of their company to reach financial goals and acquire work, rather than creating value for clients.

Value creation system	Value proposition	Revenue model
Human resources and qualifications	Lowest cost	Payment according to contract and progress
Tender preparation	According to the plan	Change orders
Financial resources	No defects	Additional work
Construction management	References	Financing form client

Table 6 Traditional anything to anyone business model (Pekuri, 2015, p. 57)

Although there are different explanations and a wide range of business models adapted to the construction industry, it is difficult to identify a unique characteristic in the existing business models of construction companies. Even though it cannot be implied that all the construction companies have a generic business model, based on the findings of Pekuri (2015) it can be stated that business models of construction companies are rather similar. Meanwhile, the literature states that business models of companies can provide an advantage over competitors when differentiating their way of doing business from others (Johnson, Christensen, & Kagermann, 2008). According to the interviewees, this mainly relies on the know-how, since this influences the price estimation and thus can eliminate the competition (Pekuri, 2015).

4.4 Business Model Canvas for Construction Companies

There are many tools available that help organisations (re)-designing their business model. 'The Business Model Canvas' of Osterwalder and Pigneur (2010) is the most frequently used business model. This popular tool helps to design a Business Model and consists of nine elements, the so-called 'building blocks': The customer segment, Value Proposition, Channel, Customer Relationship, Revenue Stream, Key Resources, Key Activities, Key Partnerships and Cost structure (Mokhlesian & Holmén, 2012).

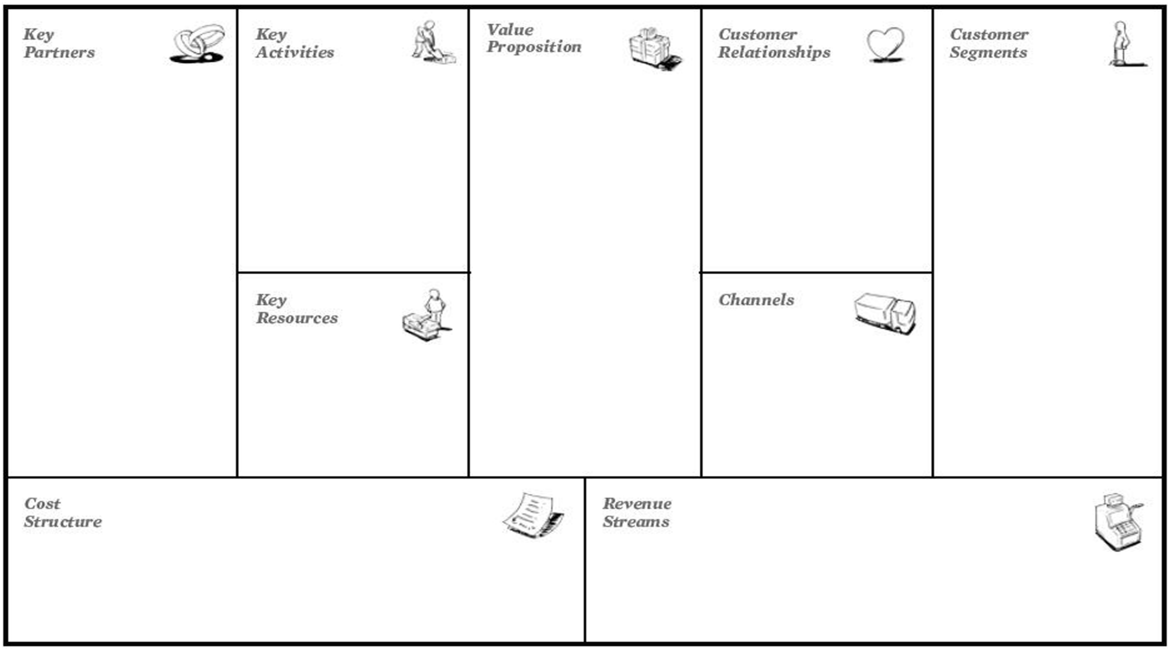


Figure 18 Business Model Canvas (Osterwalder & Pigneur, 2010)

The first building block, the value proposition gives an overview the services and products a company delivers to its clients. The second building block, customer segments describe the client for who the products or services is initial meant. In the third building block, customer relationships, the relation between the products or services supplier with the client is explained. Channels is the fourth building block, in which the way a supplier gets in touch with his client is shown (Osterwalder & Pigneur, 2010). The fifth element is the key activities, here all the activities needed to produce the product or to deliver the service will be described. The sixth block, the key resources, explains all the human, technical and financial resources a business needs to have in order to be able to execute the activities. The seventh block, the key partners, is referring to all the partners who are involved in the product or services. Without the key partners, a product or services cannot be delivered to its customers. The last two blocks are the financial blocks. The revenue streams, the eighth element, illustrates the different incomes of services and products. While the last block, the cost structure shows all the different costs which incurred to produce or deliver the services of products to the customer (Osterwalder & Pigneur, 2010). The business model canvas focuses on designing a business model for individual companies (Bouwman, et al., 2012).

In the paragraphs below, all the elements of the business model canvas will be explained for construction companies in general.

4.4.1 Value proposition

The value proposition is the benefit of an offer from the perspective of a customer. In this case of the construction company will deliver row-houses (Mokhlesian & Holmén, 2012). This value of this construction project is characterized by long lifetime. Since a building is a one-off product it is not comparable to manufactured products (Kibert, Sendzimir, & Guy, 2000). In general, a construction company build a project, according to the plan, without any defects and for the lowest cost (Pekuri, 2015).

4.4.2 Customer segment

Initially, the customer of the construction project is the customer. In case of a row-house project this can be for example a developer or housing association. However, the initiating party is in most cases not the owner of the end product. Due to the long lifetime of a building, several owners and/or users of the building will pass by (Ofori, 1999). In general, the customers of buildings can be categorized as public governmental clients, private corporate customers and individuals (Blackmore, 1990). Of all the stakeholders involved, the clients are seen as the most important stakeholder in the construction industry; they shape the project and the process according to their requirements (Qi, Shen, Zeng, & Jorge, 2010).

4.4.3 Customer relationship

The customer relationship in the construction industry is always established in a contract, in which the arrangements and deadlines of the final products and services are described. They must be stipulated in a way that the contractor can fulfil them in the agreed duration of the project and should be verified by the client (Mokhlesian & Holmén, 2012). In general, there are two types of contracts for contractors: traditional and integrated contracts. In traditional contracts, different tasks are the liability of different actors. Examples are general contracting, building team, joint venturing and subcontracting. Integrated contracts are used when one party is liable for the entire project. This can be with financing such as in contracts as Design Build Finance Maintenance and Operate. Or without financing such as main contracting, Turnkey Contracting, Design & Construct and Design & Build contracts (Roelofs & Reinderink, 2005).

4.4.4 Channels

Limited information is found in the studied literature about this specific element of the business model. However, one channel became clear. In the current construction industry, projects are primarily acquired by tenders (Pekuri, 2015; Mokhlesian & Holmén, 2012). In the construction industry tenders are mainly won on the lowest bid. However, there are also tenders with other requirements such as most sustainable or highest quality.

4.4.5 Key activities

The key activities of a construction company depend on the contract made. However, since a construction company of origin build the project itself, it can be assumed that construction companies at least are responsible for the construction of the building. This does not mean that they have to execute it themselves. For example, in case of a sub-contracting, they can outsource this activity to a sub-contractor. Other activities which construction companies can execute are tender preparations, design, development, engineering, maintenance, management and also bearing the risks (Pekuri, 2015).

4.4.6 Key resources

In general, the construction companies need three types of resources: human, financial and equipment. Humans resources, with required qualifications are needed to prepare, manage and execute the work according to the contract. Financial resources are needed in order to pay all the bills and cover risks. Lastly, equipment such as machineries are needed for onsite construction; equipment is also necessary for accommodation and transportation (Pekuri, 2015).

4.4.7 Key Partners

Key partners are dependent on the construction project and the activities of the main contractor (Mokhlesian & Holmén, 2012). The supply chain in construction consist of all the organizations and parties involved in the whole process, starting from the initiation phase till the operation phase and from the extraction of materials to the demolition of the buildings (Ofordi, 2000). In spite of the large amount of different parties involved in the construction process, it is important to manage the complete network. A strong collaboration between the parties is required since the performance and competitiveness in the construction industry depend not only on the main contractor, but on the entire supply chain (Gann & Salter, 2000). Examples of partners are manufacturers and suppliers of construction materials, architects, designers, consultants and external carpenters (Segerstedt & Olofsson, 2010; Dubois & Gadde, 2000; Pekuri, 2015).

4.4.8 Cost structure

The cost structure of construction companies consists of direct and indirect costs. The direct costs cover all the materials and components which remain in the constructed building (Economisch Instituut voor de Bouw , 2011). The indirect costs or general construction costs includes of all the equipment needed on the construction site, the labour costs of the carpenters etc. (Rip, n.d.). Besides the direct and indirect costs, there is also an expense in which all the remaining costs are covered such as the general costs for accommodation of the company and wages of directors and other general staff members. In addition, general costs include insurance costs, risks etc.

4.4.9 Revenue streams

In the construction industry, the payments are according to the activities and progress, which are stipulated in the contract. Changes in the design and construction will increase the revenue streams because, in general, this will lead to additional costs for the contractor. The revenue stream is financed by the customer (Pekuri, 2015).

4.5 Conclusion

This chapter answers the question 'What does the current business model of construction companies look like?' based on findings in the literature.

Recently only one study is done to the business models of construction companies. Pekuri (2015) conducted several interviews to gain insight into the business models of construction companies in Finland. In his research, he explains that the construction industry is a project-based business, with a large supply chain, which makes this industry risky and reactive (Mokhlesian & Holmén, 2012). The innovations that has been implemented are technologies developed by other supply partners (out-side innovation). In order to facilitate innovation, it is important for managers to understand the business model because this will provide a starting point for construction companies to innovate. In addition, the unawareness of the business model will reduce the effectiveness and hinder performance (Höök & Stehn, 2014). As a result of Pekuri (2015) his research, it can be stated that there is no general definition of business models in the construction industry, not between different companies and neither within a company similar descriptions are given. Furthermore, the use of business models in construction does not correspond with the literature. According to the literature business models evaluate the suitability of a project within a company. However, since the construction is a project-based business, they rather focus on a cash flow stream by acquiring enough projects, than being selective. Therefore, the construction industry is seen as 'anything to anyone' business (Pekuri, 2015). Business models in construction are used to reach financial goals and acquire work, instead of creating customer's values. From the research of Pekuri (2015), it can be concluded that there is no general business model for construction companies available. Although the definitions and elements are different, there is no single unique characteristic. Therefore, it can be stated that construction companies have rather similar business models.

C METHODOLOGY

5 METHODOLOGY

This chapter describes the research methodology, in which the research approach and the used research methods are briefly described. These methods are used to answer all the sub-questions.

5.1 Research approach

This graduation research is a hybrid research; it consists of both an empirical and formal research part. The empirical research aims to produce theoretical knowledge, based on current and past experiences (Barendse, Binnekamp, Graaf, van Gunsteren, & van Loon, 2012). This descriptive form of research is used to: First, understand the current business model of construction companies and second to investigate which changes occurred in the business model of another industry due to robotisation. This comparison is used in the second part of this research, the formal part. In general, formal research is conducted to improve future situations by creating an operationalised artefact (Barendse, Binnekamp, Graaf, van Gunsteren, & van Loon, 2012). In this prescriptive part, an adjusted business model will be designed to make on-site robots possible for construction companies.

5.2 Research methods

This section of the research provides guidelines for data collection methods to be used in this research. Besides that, the choice of the specific methods and relevance is argued.

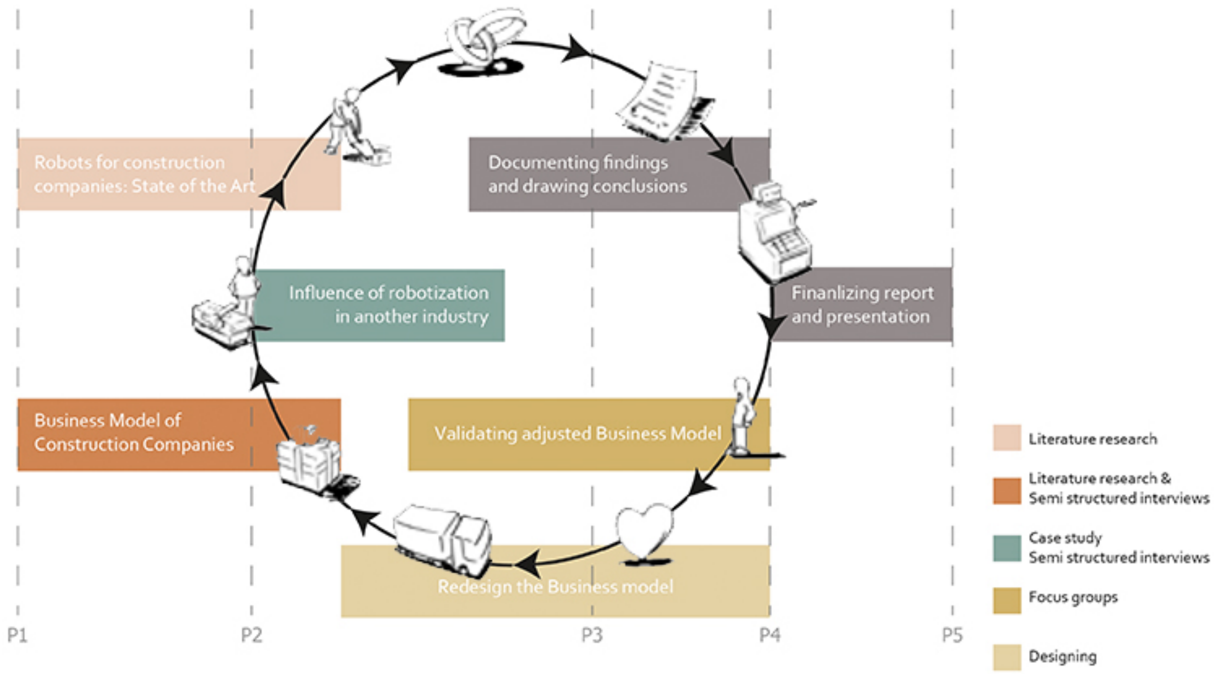


Figure 19 Research methods and planning (Own image)

5.2.1 Literature research

The first stage of this research involves reviewing the existing literature of robots for the construction industry. Literature research provides the state of the art of robots for the construction site. Several articles of journals, academic reports and books are used to provide an overview of the current state of the art of robots for the construction site. Since Japan is a precursor of robotics, a lot of sources are originated from Japan. It was assumed that the specific employment of the robot would influence the business model. Therefore, based upon the gained knowledge a specific robot is chosen.

Moreover, a literature research is conducted to understand the current business model of construction companies. Although the focus of this research is the Dutch construction industry, there is no valid literature available specified on the Dutch construction sector. Therefore, European literature (articles, reports and books) is used to describe the business model of construction companies. literature sources about business models are in general used to find a framework to display the business models of construction companies. The business models of construction companies in this research are limited to the residential sector.

Finally, several literature sources, such as articles, books and reports are used during the case study to understand the robotised industry and the change in the business model due to robotisation.

5.2.2 Selection of the robot

In literature, thirteen tasks are found which can be executed by on-site robots for construction. Multiple criteria have been taken into account, in order to select a specific construction robot. In Table 7, all the available on-site construction robots are rated according to six criteria. According to the literature, all the robots below can execute jobs on the construction site. However, not all the tasks are associated with the construction of row-houses. Therefore, the first selection criterion is based upon the association with the residential construction practice. The second criterion select the robots on their share in the construction process of row houses. Tasks which have a minimum share in the construction process of row houses are marked with an L, tasks which have medium share are marked with an M, and tasks with a high share in the construction process are marked with an H. As third criterion, the share in cost is rated. Although some tasks have a high share in the project, the share of costs can be limited, or the other way around. The fourth aspect is the interest of Dutch construction companies in the robotisation of specific tasks, this is based upon the interviews held with the eight largest construction companies in the Netherlands. The fifth rating is based on the expected impact of the robot in terms of productivity. And in addition, the last aspect is rating the expected decrease in construction costs. Although in general the ratings are based on the findings in literature and interviews held with construction companies, the last two criteria are not rated based on expectations, which is not objective at all.

Robot	Residential construction practice	Share in the process	Share in the costs	Interest of construction companies	Expected Increase productivity	Expected decrease of costs
Assembly	✓	L	L	✓	L	M
Building skeleton erection	✓	H	H	✓	H	H
Coating of fire protection on steel	X	X	X	X	X	X
Concrete distribution	✓	L	L	X	L	L
Earthwork	✓	L	L	X	L	L
Interior finishing (painting, plastering, tiling)	✓	H	L	✓	M	M
Lifting heavy elements	✓	L	L	X	L	L
Masonry	✓	M	M	✓	H	H
Removal of old coating	X	X	X	X	X	X
Road paving	X	X	X	X	X	X
Surface finishing (concrete, tile-setting)	✓	L	L	X	L	L
Welding	X	X	X	X	X	X
Window glass mounting	✓	L		X		

Table 7 Selection of robot (Own table, based on the literature study)

According to the rating system, a building skeleton would have the biggest impact on the construction industry and would be most promising for this research. Although this robot is mentioned in several literature sources, it turned out that such a specific robot is not for sale yet. However, the technology of 3D printing or Additive Manufacturing (AM) is currently far enough developed and available in the Dutch construction market. This technology uses concrete to print walls, although initially a 3D concrete printer is not included in the definition of a robot formulated for this thesis:

A robot is a smart, multitasking machine, controlled by a computer which is attached to a movable physical body, which (semi) automatically performs jobs and can react to its environment based on given data, calculations and own observations.

A 3D printer or 3D printing robot is a static robot arm, as used in the manufacturing factories. This robot arm is connected to a computer which drives the robot based on imported drawings. A nozzle prints fast drying cement, layer by layer. All the layers of concrete together will produce a wall element. However, this robot can be placed on a car, which makes the robot (manually) movable. Therefore, the 3D printing robot is also able to print on-site. In addition, at this moment the 3D printing robot is not able to react on its observations. However, technology is developing rapidly, and 3D printing is assumed to be highly promising. Bouwkennis (2016) predicts that 3D printing will have the biggest impact on the construction sector in the upcoming years (See chapter: 1.1.3 Potential technological trends for the construction industry). ABN AMRO (2016) analysed an annual increase of 30 percent of investments in 3D printing.

Since the 3D concrete robot printer is available on the Dutch market and is a proven technology, which meets the Dutch construction standards. This 3D printing robot is used in this thesis, in order to find out the changes that need to be made in the current business model of construction companies, to make an on-site robot possible.

Figure 20 Dutch 3D concrete printing company (Heijmans, 2016)

5.2.3 Explorative interviews

Based on the chosen on-site robot, an explorative interview with the robot developing company are held. This interview is used complementary to the literature research since the specific published information about the robot will be limited. To avoid missing necessary information, a semi-structured interview is prepared, see appendix 14.5 and 14.6. This still offered the possibility to interact with the interviewee, avoid limitation and ensures that all the required questions are asked (Bryman, 2012). Since there is only one 3D-concrete-printer manufacturer in the Netherlands, this company is selected for this explorative interview. Based on the commercial information needed, the business developer of this company is interviewed. Due to the background of the interviewee, the business developer of a commercial party, who likes to sell his product, the obtained information is assumed as valid. The 3D printing robot is already used in practice. The interview is replicated during the end of this research, to see whether the conditions and financial information, might have changed, due to the developments of this company, see appendix 14.7. These interviews are recorded and transcribed for the reliability of this research. These transcripts are reviewed by the interviewee (respondent validation). 'Respondent validation involves research participants responding either to forms of initial data, for example, transcripts of interviews, or observations of activities, in order to check them for accuracy, or to first drafts of interpretive reports to respond, again, for their accuracy, but also to the interpretive claims that are being made' (Torrance, 2012, p. 114).

The knowledge gained during the interviews are used as input for the financial part of the business model, the revenue streams and cost structure.

5.2.4 Semi Structured Interviews

Semi-structured interviews are held to find out how the current business model of construction companies look like in practice. The interview format is included in appendix 14.1. The questions and order of the semi-structured interviews are based on the Business Model Canvas of Osterwalder & Pigeur (2010). Prior to the interview, the interviewee received an e-mail with the explanation of the business model canvas and the questions so that they could prepare for the interview. Since there is limited literature available on the current business models, and no literature available about business models of Dutch companies, multiple interviews were held to complement the literature. These interviewees, preferably directors, should be involved or have an understanding of the business model of their company.

The size of construction companies influences the focus, role and position of the construction company. Therefore, only the largest construction companies active in the construction of row-housing in the Netherlands are part of this research. However, in order to find out if there is indeed a difference in medium and large size companies, also one medium size company is interviewed.

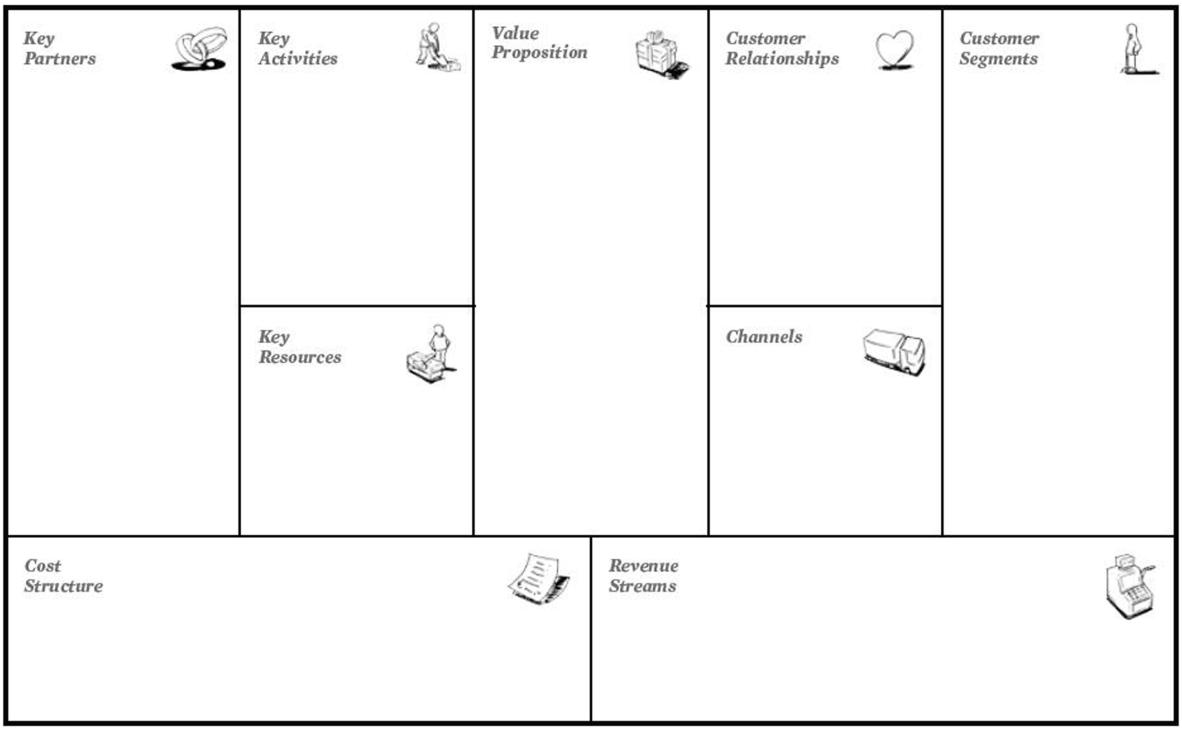


Figure 21 Business Model Canvas (Osterwalder & Pigneur, 2010)

For validation, all the interviews are recorded, transcribed and are reviewed by the interviewee for creditability. In addition, the information collected during the interview is displayed in the Business Model Canvas of Osterwalder & Pigneur (2010). This canvas is used as a framework for collection all the data of construction companies. Another measure regarding the validity is the responds validation of the Business Model Canvas. After conducting all the interviews, one merged business model is made, with all the given answers provided by construction companies per building block. With this generic business mode as inspiration, construction companies could review their own business model canvas and completed their business model when needed.

5.2.5 Case study

A case study is a method to collect, analyse and compare empirical data of practice (Yin, 2003). For this research, a case study is conducted in an industry which recently implemented robots. In this way, the change of a business model of a traditional company towards a robotised company became visible and could be used as inspiration for the design of an adjusted business model for construction companies. In chapter 2.6 Robotisation in other industries, an overview is given of industries which are currently using robots. In order to find a suitable industry, the following selection criteria are applied to the industries found in literature:

- The case study has to be conducted in the Netherlands.
- The chosen company must have undertaken the transition from tradition towards a robotised company.
- The company should be part of a supply chain.
- The robot(s) should be used for the own production or construction of the company.
- The robot(s) has to replace human production tasks.
- The robot(s) used in this industry is preferably a mobile (on-site) robot.

Taking these criteria into account, dairy farms are a perfect example of an industry that recently has been robotised.

For this case study, a literature research is done, complemented with a validating semi-structured interview to show the changes in the business model of the specific companies. A requirement for the interviewees was that they should have been active in a traditional and robotised company and have knowledge about the business model or strategy. The semi-structured interviews are based on the Business Model Canvas of Osterwalder and Pigneur (2010). Prior to the interview, the interviewee received an e-mail with the explanation of the Business Model Canvas and the questions so that they could prepare for the interview. The interview protocol is illustrated in appendix 14.8. The information conducted during the interviews is again displayed in a business model canvas framework.

For the validity of the case study, two interviews are conducted with different dairy farms. According to Bryman (2012) triangulation, the use of more than one method or source of data will control the validity. Findings of the cases can be cross-checked. In addition, the interviews are recorded and transcribed. Together with the created Business Model Canvas, this is checked by the respondent. The respondents had the chance to review and complete the business model framework.

5.2.6 Designing

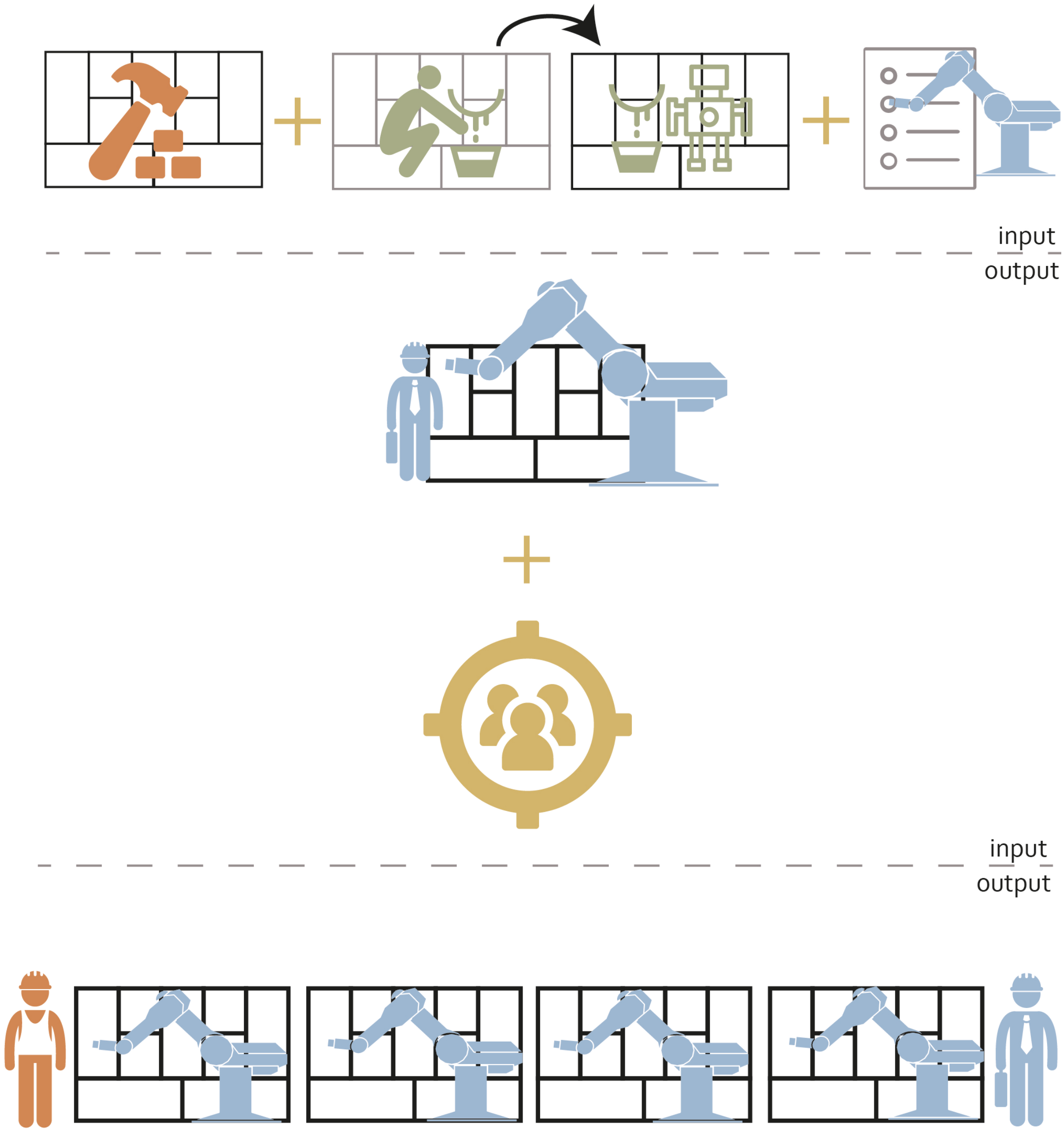


Figure 22 Input for the adjusted business model (Own image)

The findings of literature and empirical research are used as input in the operational part of this thesis. The current business model of construction companies is the fundament of the adjusted business model. This current business model is changed with the input of the findings from of the dairy farm case study and with the specification of the chosen robot, the 3D. For the design part, the Business Model Canvas (Osterwalder & Pigneur, 2010) is used as a framework in which the adjusted business models will be illustrated. The design process consists of two phases. In phase one a draft design is made, which is validated by a focus group of professionals of the construction industry. With the input of the focus group the second design phase starts, in which the final design is made.

5.2.7 Focus groups

A focus group is organised to validate the newly designed business models. A focus group is a suitable method to validate data since all the participants are free to speak, to bring forward the things that are deemed to be important or significant (Bryman, 2012). The members of this focus group are all professionals of several big construction companies, preferably the ones who participate in the semi-structured interview, so they are familiar with the topic and understand the way a business model works and understand the business model canvas. The composition of the focus group is heterogeneous, different kind of construction companies are presented, medium and big size companies. The group consisted of four participants. In appendix 14.12, the invitation of the focus groups is added as well as a summary of the findings of this focus group.

D PRACTICE

6 BUSINESS MODEL OF CONSTRUCTION COMPANIES IN PRACTICE

This section demonstrates the current business of the largest construction companies of the Netherlands. The information of this section is collected by means of eight semi-structured interviews held with seven of the largest construction companies in the Netherlands and one medium size company. First of all, the definition of a business model according to the interviewed companies are given. Secondly, the use of the business model in practice is explained. This chapter concludes with an analysis of the different business models, by using the business model canvas of Osterwalder and Pigneur (2010). This chapter, together with chapter 4 Business model of construction companies in theory, gives an answer to the sub-question: 'What does the current business model of construction companies look like?'

6.1 Definition of a business model by practice

In this research, the similar question has been asked as in the study of Pekuri (2015): What is the definition of a business model and where is it used for? This question has been asked to the interviewees of Dutch construction companies, mainly directors or managers of the business department, who are expected to have knowledge about the strategical and operational level of the company. However, during the interviews, it turned out that explaining the definition of a business model was perhaps the most difficult part of the interview. Although the interviewees received an interview protocol prior to the interview, some interviewees slightly panicked because of this question. In general, it can be concluded that all the definitions given by the interviewees differ from each other. However, in seven out of the eight interviews the interviewee, explained a business model by referring to the earnings and financial profitability of the company. Only one company stated that a business model is something different than an earnings model. According to this interviewee, an earnings model is the base of a business model (Interview Company 2). Therefore, it can be concluded that construction companies do not see a difference between business model and earnings model.

'The business model, is the way you earn money or?' – Interviewee Company 3

'I always think of an earnings model, when talking about a business model. And if I think of earnings model, I always think for what service or product is the customer willing to pay.' – Interviewee Company 5

In some cases, the definition of the business model is supplemented, by the value in terms of a project or service that the company proposes to the customer and the added value of this product (Interview Company 5 & 6). Others add that a business model should explain how a business sustains (Interview Company 1, 2, 6 & 8). Furthermore, one interviewee described a business model as a playfield, the areas in which a company operates (Interview Company 8).

There is only one company which shows an implicit business model during the interview. However, this business model does not include earnings at all. This model is two-sided, half of the business model is used to explain to the customers (external) what the company is offering, in terms of for example specific residential concepts, but also the specific fields in which they are operating. The other half of the business model is used internally, as a method for the employees, to show how the work should be done but also to indicate internal employees' satisfaction and opportunities for employees (Interview Company 7).

Besides, in two of the three interviews held with multiple employees, there was none corresponding internal definition of a business model given. During two of the interviews, the interviewees supplemented each other (Interview Company 3 & 8)

6.2 Use of a business model in practice

The interviewees all confirmed that, nowadays, a critical selection of projects takes place. This has been different during the crisis, in which all the jobs have been accepted to ensure continuity of work. Except for one company who uses a separate sheet for the selection of projects (Interview Company 6), all the other companies claim to use their business model as a filter for these selections.

In the hard years of the crisis, Company 5 almost collapsed. By focusing on only the projects where they good at and acquisition by an international concern they revived. This focus is determined in their business model. Before the acquisition of a project, the suitability of a project is first checked by means of the business model (Interviewee Company 5).

6.3 Current business model in practice

The information collected during the interviews with the construction companies is used to design separate business model canvas for the interviewed construction companies. These are attached in appendix 14.2. During the interviews, it became clear that projects with different construction methods within the same construction companies, use different business models, because the construction method influences the construction time and thus the time-related costs, also the needed materials and equipment differ in price, the flexibility and adaptability of the project depends on the method and last the number of actors involved is based on the chosen construction method. An overview of the different construction methods and its influence is available in Chapter 3.3 Construction methods. However, since masonry with lime sandstones and prefabrication are the most used construction methods for row-housing in the Netherlands, only these two methods are researched. In this following chapters, masonry construction with lime sandstones is called the traditional way of building, while the prefab method refers to both prefabricated elements and prefabricated unit method.

This section will continue with a comparison of each building block, in which both the construction methods as the different construction companies are compared.

6.3.1 Value proposition

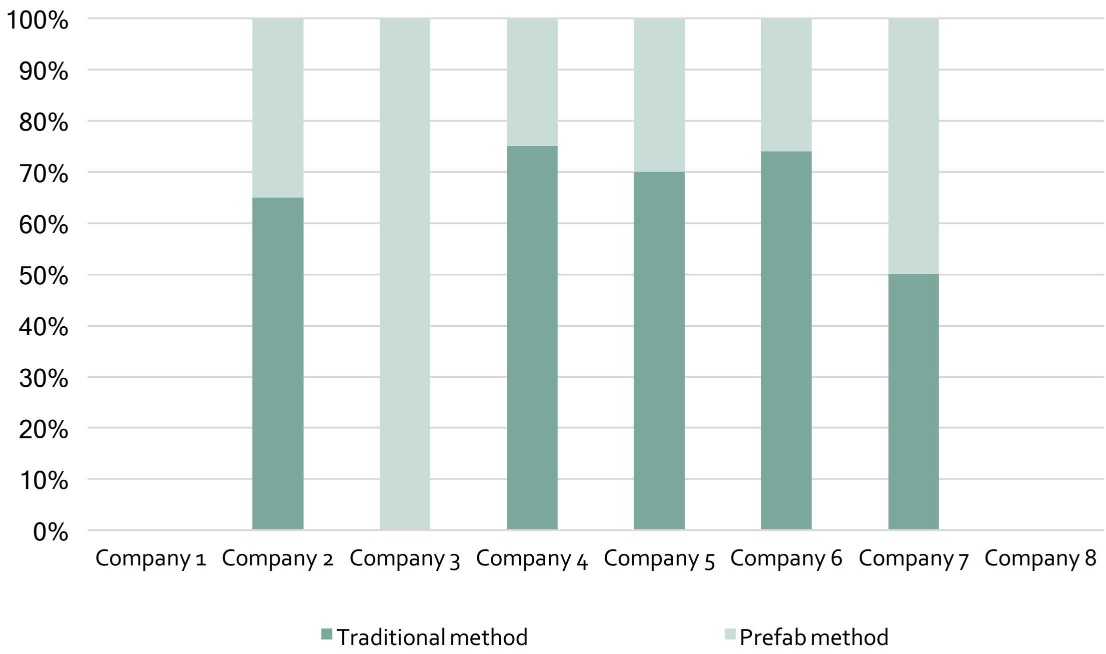


Figure 23 Ratio traditional and prefab projects (Own figure, based on the held interviews)

In general, there are two types of products which can be distinguished in the category row-housing: the traditional dwellings and the prefab concept house. Most of the construction companies, 7 out of 8, build both kinds of houses, only one company has stopped building traditional houses. The choice for the construction method is amongst others based on the scale of the project and the size of the construction site, project planning, the available equipment and workforce and the budget of the project. Although construction companies used to participate in tenders on the lowest bid, only one company admit to still sign up for this kind of tender. Half of the participants, aim for the best-priced houses, which means that they try to offer the best price for the quality delivered. By means of the prefab construction method, the construction time drastically reduced, from months to weeks. Two companies add this to their value proposition; they propose the fastest built house to their customers. Another aspect which has grown over the years is the flexibility and adjustability of the dwelling. Users would like to buy a house, which is custom made, however with the traditional construction methods, adjustments are still possible till the end of the construction phase but this is complicated and highly expensive. Prefab housing has the advantage that it can easily be adapted to the demands of the resident. However, customers should be early involved to adjust the property. Since the houses are produced in the factory, changes should be made at an early stage. Six of the eight companies anticipate on this. The last aspect that is important for three of the interviewed companies is to realize a sustainable home. Despite the possibilities of prefab construction, the majority is still traditionally built.

6.3.2 Customer segment

There are three categories of customers for the construction of row-houses: Internal client, External client and (end) Users. All the large construction companies have an own internal development department, with the purpose to ensure the continuing flow of projects within the company. The medium sized company interviewed, was indeed fully focused on the construction process and has no internal development department. The external clients consist of external developers, funds, housings associations and investors. Of this Dutch construction companies, only one company executes jobs for individual clients. All the participated companies keep their end user in mind: the buyer or tenant of the house.

6.3.3 Customer relationship

The relationships of the construction companies with their clients are in generally two-sided. The construction companies mainly have a long-term relationship with the initiator: the investor, developer, fund or housing association. They often collaborate with a project team, and accompaniment and service are offered. However, the direct relationship with the user depends on the function of the built dwelling. In case of a rental property, there will not be any contact with the user. The other extreme is co-creation, which is applicable to seven of the companies, when the construction project is for sale. In particular, prefab construction projects, aim to be co-created. A special department guides the buyers and advises them on their choices. In all cases, the buyers and tenants can contact the service department in case of defects. In addition, there is a legal relationship between the construction company and the clients. The appointments made are recorded in a contract. Although there are many different contracts, the interviewed companies just spoke about Design & Built and Design, Built and Maintenance contracts.

6.3.4 Channels

The main channels to acquire projects is to participate in tenders or selection procedures. In addition, the importance of a network is mentioned several times by the interviewees. In most of the cases, this refers to an external network. However, the internal relationship with the development department within the company can also ensure projects. Furthermore, (online) marketing, showrooms and information evenings are added to channels. The latter mainly concern the sale of residential properties to the users.

6.3.5 Key Activities

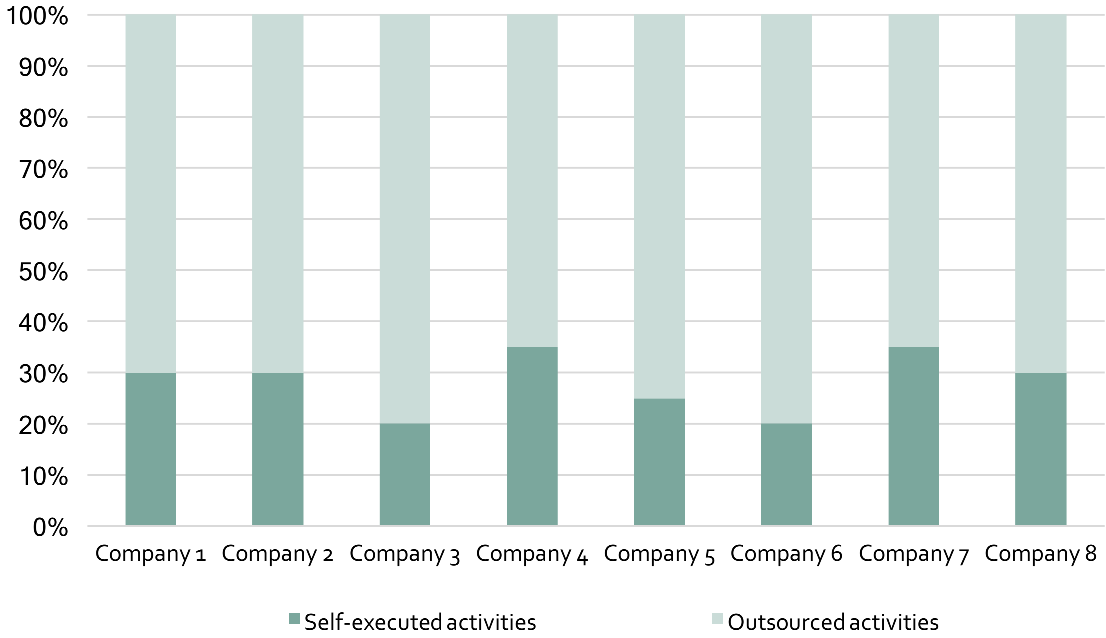


Figure 24 The own and outsourced share in the construction process (Own figure, based on the held interviews)

The interviewed construction companies suggest that they built, although only three of the interviewed companies add built to their main activities. This emphasized by numbers in which the own share of the construction process is taken into account, none of the participated companies is responsible for more than 35 percent of the realisation of the process. The medium-size contractor has a similar share in the construction process. This is illustrated in Figure 24. In general, construction companies coordinate, organise, manage, guide and drive the construction process, rather than taking part in the construction itself. They see themselves as a link between all the involved parties, where they add value through their knowledge of the construction process. Besides, not all the companies add calculation and planning to their key activity list. As stated before, all the large construction companies are active in the field of development, which they also see as one of their key activities. Furthermore, six out of the eight companies are involved in the maintenance of (rental) dwellings. Only four of them mention this as a key activity; the others outsource this job to a sub-contractor. Finally, three companies add transformation or renovation to their key activities.

6.3.6 Key Resources

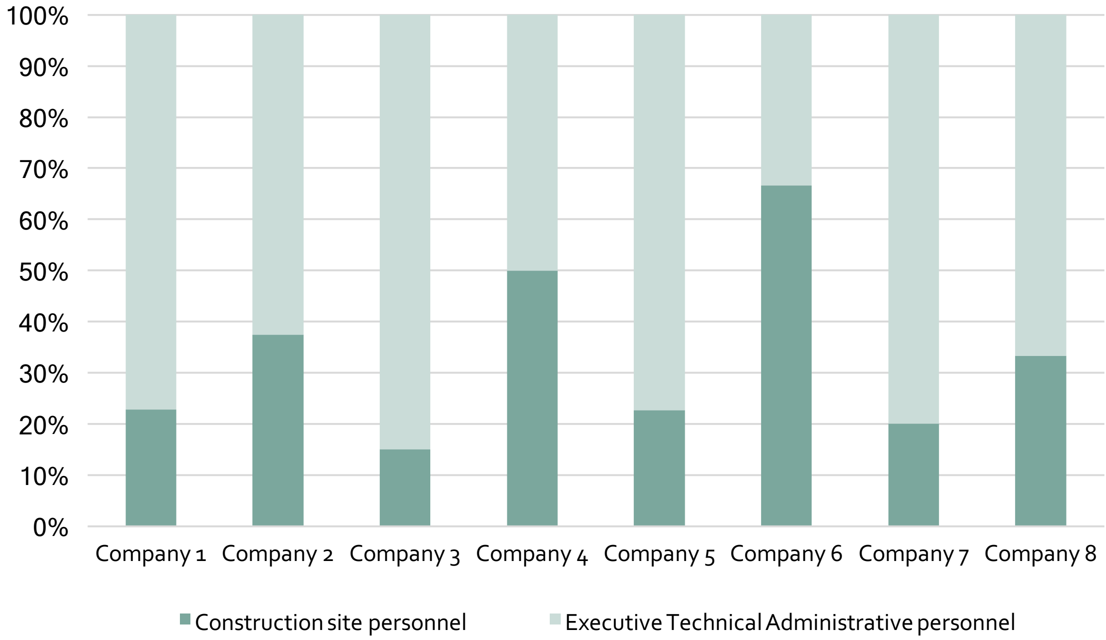


Figure 25 Ratio of the human resources (Own figure, based on the held interviews)

The key resources of construction companies consist of an enormous number of different elements. However, during the interviews, only the elements important for the construction of row-houses have been discussed. First of all, the human resources; Construction companies categorise their employees into construction site personnel (Dutch: CAO) and Executive Technical Administrative personnel (Dutch: UTA). Also, here the changing role of the construction companies is visible. See Figure 25. Six out of the eight companies have significantly more Executive Technical and Administrative personnel employed. One company has as much construction site as executive technical and administrative personnel in-house. Moreover, it is remarkable to see that the only company with more construction site employees is one of the large construction companies and defines build not as their key activity. Based on the in-house knowledge of employees, one construction method can be preferred over another. Especially masonry, which becomes expensive to outsource, will earlier be applied when there is an in-house mason. This is the same with the casting method. However, this is excluded from this part of the research.

Besides the human resources, the equipment service is an important resource for the construction. All the large construction companies have their own equipment service. Although this belongs to the specific company or concern, this is mainly an own entity. The used equipment is rented by the own company. In general, the equipment service only has the widely used and non-specific tools. More specific equipment needs to be rented elsewhere. The medium size company has not an own equipment service. In addition, fifty percent of the interviewed companies purchased a prefabrication factory for the production of the prefab elements or even modules. This influence the choice of construction method, because it is for their own good to ensure a continuity of work in the prefab factory. Therefore, the choice for prefab is obvious.

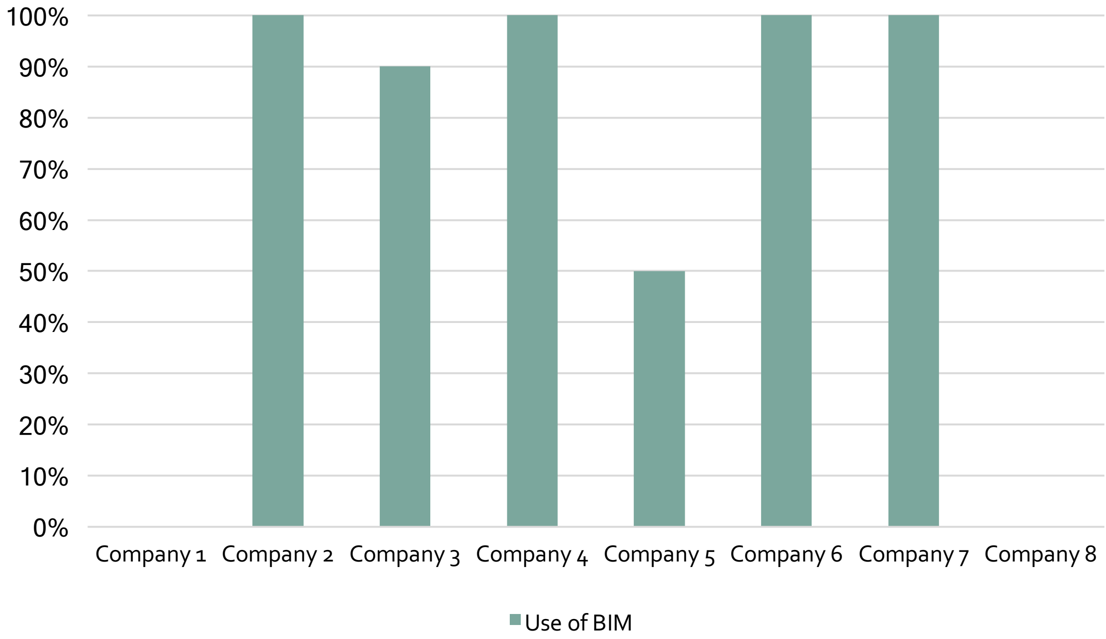


Figure 26 The use of BIM in the residential department (Own figure, based on the held interviews)

For the preparation, but also during the construction process ICT and BIM become more and more important. The interviews revealed that all the companies are actively using BIM. To be precise, four of the six respondents use BIM for all of their residential projects. With increasing applied prefab method, the percentage of BIM use will increase.

Finally, two companies quoted network as an important resource to acquire work and also a network of partners to whom they deliver the project.

6.3.7 Key Partners

	Prefab process	Traditional process
Sub-contractors	Architect Assembly team / Structural Work team Carpenters / Finishers Constructor Consultants Demolition team Electricians Facade builders Installer (Boiler, Ventilation) Interior designer Maintenance companies Masons Painters Plasterer Plumber Roofers Tiler	Traditional partners sub-contractors Architect Carpenters / Finishers Constructor Consultants Demolition team Electricians Facade builders Installer (Boiler, Ventilation) Interior designer Maintenance companies Masons Painters Plasterer Plumber Roofers Tiler
Suppliers	Brick supplier Concrete supplier Equipment supplier Facade supplier Floor supplier Foundation supplier Frames supplier Installation supplier Interior wall supplier Prefab factory Roof supplier Roof tile supplier Sanitary supplier Staircase supplier	Block / Limestone supplier Brick suppliers Concrete supplier Equipment supplier Facade supplier Floor supplier Foundation supplier Frames supplier Installation supplier Interior wall supplier Prefab factory Reinforcement supplier Roof supplier Roof tile supplier Sanitary supplier Staircase supplier Structural Work team

Table 8 Key Partners per construction method (Own table, based on the held interviews)

The key partners of construction companies can be divided into sub-contractor and suppliers of elements and materials, as illustrated in Table 8. The number of partners differs depending on the construction method. Generally, it can be concluded that the traditional process requires more partners than the prefab process, as shown in Figure 27. However, this depends on the level of prefabrication. Although most companies work with prefabricated elements, mainly walls, there is also one company which produces prefabricated modules including complete bathrooms. This, of course, decreases the number of partners drastically. For this research, it is important to remark that although the construction companies have their own construction site personnel, additional support is necessary from partners for the construction of the shell (Dutch: Casco). In order to assemble the prefabricated elements, three out of the eight construction companies need the help of external assembly or structural work teams. For the traditional construction method, even more external help is needed. Six of the seven companies, need a mason to build the limestone walls. In addition, some companies also need an external structural work team.

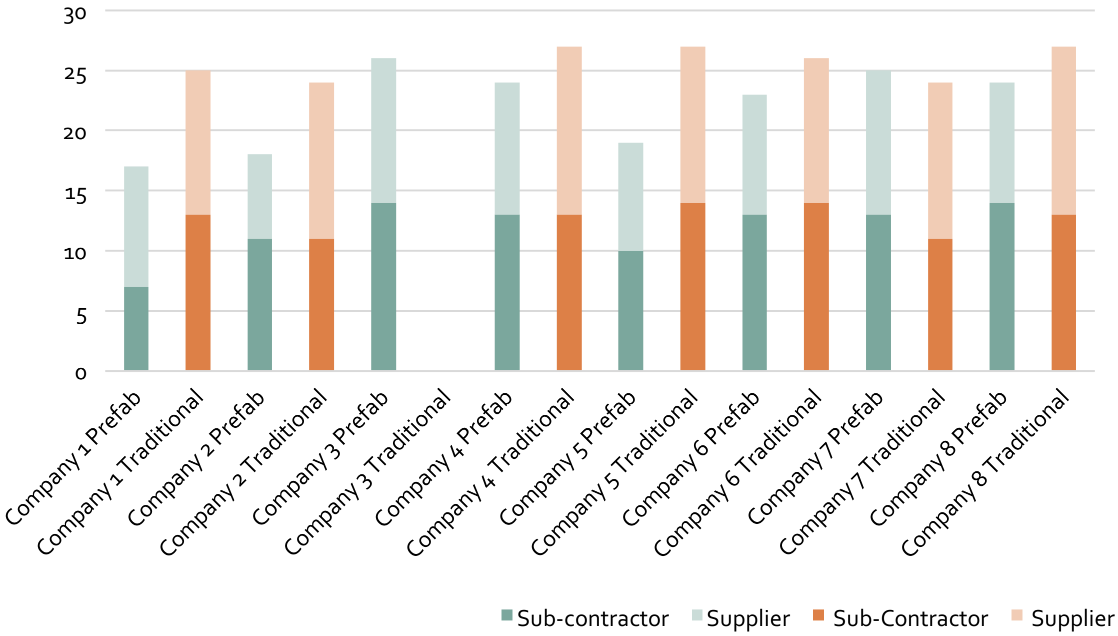


Figure 27 Number of partners needed per construction method (Own figure, based on the held interviews)

Also, the shortage of carpenters is visible in the results of the interviews. For prefabrication of row houses, fifty percent of the companies need to hire external carpenters. For the traditional process, this is even higher, six of the seven companies hire external carpenters.

6.3.8 Cost structure

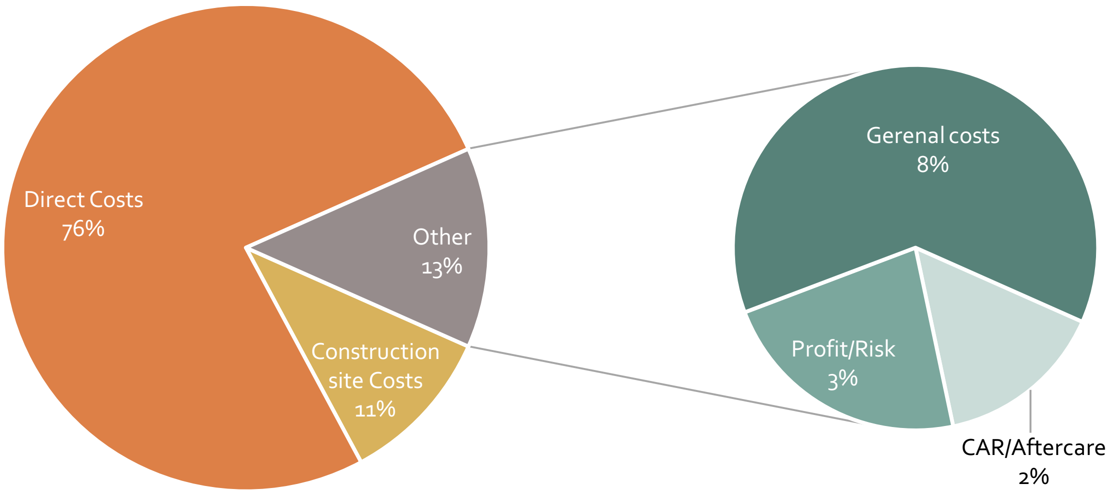


Figure 28 Average cost allocation (Own figure, based on the held interviews)

The construction costs of row-houses can be divided into direct costs, general construction site costs and other costs. The direct costs include all the materials and work that remain in the constructed property. The construction site costs include all the construction site equipment needed for the construction and the project-based personnel such as implementers (Dutch: Uitvoerders) and project managers. Since this expense consists of equipment rental and labour costs, this item is time-related. According to Gulick (2017), cost expert of Heijmans, 60 percent of the general construction site costs is time-bound. Choosing for a prefabricated house can reduce the original construction time with 50 percent, which decreases the total costs of the project.

The other costs can be sub-divided in General Costs, Risk/Profit, CAR and Aftercare. The general costs are non-project-related costs (office, project manager, administration, etc.). The risk and profit margin is calculated on the total project cost. In general, this is 3 percent for residential projects. CAR is the construction all risk insurance. And the aftercare is a budget withheld in case there are defects.

In order to get an understanding of the costs, related to the specific construction methods, a cost comparison for a prefab and traditionally constructed row-houses is executed by Heijmans. This included to this research in appendix 14.10.

		Traditional project	Prefab project
Total price difference		100 %	97,3%
Direct costs	Labour	8,2%	5,4%
	Material	17,5%	11,6%
	Equipment	0,9%	0,3%
	Sub-contracting	47,5%	61,1%
General construction site costs		16,7%	12,5%
Other costs		9,2 %	9,2 %

Table 9 Cost comparison of a traditional vs prefab project (Own table, based on numbers of Heijmans)

Based on this comparison it can be concluded that for this specific project the prefabrication method of Heijmans will be almost 3 percent cheaper than the traditional method. Not only the final costs differ, but also the ratio direct costs and construction site costs shifted, illustrated in Table 9. In the traditional situation, more construction workers are needed on-site. Therefore, the labour cost increases. In addition, the on-site construction time for traditional projects is longer, than with prefabricated projects where the elements are produced in the factory. This is why for traditional projects the Construction Site Costs are higher. For Prefab, the share of direct costs is higher. This has to do this the purchase of the prefabricated shell which (Dutch: Casco) of an external party. However, limited time and workforce are needed on site. Therefore, construction site costs turn out to be lower. In both projects, the other costs remain the same.

6.3.9 Revenue streams

The revenue streams of the company depend on the activities executed or outsourced by the construction company; the higher the degree of self-executed activities, the higher the revenue will be. In general, for the residential construction department, the main income is the profit (and risk) on the construction of the built properties. However, since the biggest part of the construction companies have own land positions and a development department, there is also revenue based on the sale of properties and developed projects. In addition, the companies who take care of the maintenance of the dwellings of for example housing associations, or the ones who transform or renovate properties will have an additional income stream.

6.4 Conclusion

This chapter illustrates how the business model of construction companies looks like in practice and answers the question 'What does the current business model of large construction companies look like?'

Analysing the business models of the interviewed construction companies, it can be stated that none of the construction companies had a unique element. The business models of consist of different combinations of elements, this is what distinguishes the models. In addition, the chosen construction method influences the business model; the value proposition changes, other customer relations can be used, the own share of the construction process influences the key activities, and thus the key resources are adjusted when choosing for another construction method. In addition, the numbers of key partners are dependent on the method used, as well as the related costs. When the activity and thus the own contribution to the process increased, or decreased, the revenue will change.

However, in general, in depended on the method the following business model can be composed: A construction company proposes row-houses to clients. Usually, these clients are not the end users of the building, but an external or internal business. Here, a relationship is established with, in any case, the initiator of the project. The agreements made, are stipulated in a contract. Dutch construction companies are largely involved in tender and selection procedures, in order to acquire work. The changing role of the contractor becomes clear when looking at the key activities of the construction company. They aim to organise, manage and bring together all several partners, who then perform the executive tasks within the construction process. The number of partners and own activities determine which internal resources are required to build the house. All partners, internal employees, materials, and equipment must then be paid. These costs are divided into direct costs, general construction costs and other costs. Ultimately, the house and the service of the construction company provide income. This makes the construction industry profitable.

7 INFLUENCE OF ROBOTISATION IN ANOTHER INDUSTRY

In the past twenty years, the dairy industry has changed. The traditional industry is today innovative and, in some cases, almost completely automated. As inspiration for this graduation research, a case study has been conducted at dairy farms to see how their business has changed due to the advent of robots. First, the industry is introduced, and the motives for changes are explained, followed by a section on the applicability of the robot. After that, the change caused by the advent of robots in the business model of dairy farms is described. Finally, this chapter ends with the pros and cons of robotisation in this sector. This provides an answer on the sub-question: 'How did the business model of another industry change due to robotisation?'

7.1 Introduction to the dairy farm industry

Since the nineties, several manufacturers have developed robots for the dairy industry. These developments were driven, amongst others, by the growth of the world's population. By 2050, nine billion world's citizens are expected, who all need to be fed. Therefore, the productivity of the agricultural sector must increase (Brabantse Ontwikkelings Maatschappij, 2015).

The heavy working conditions in the dairy industry and the bizarre and inflexible working hours have caused a shortage of employees in this sector. This industry has a high labour intensity, and with the highly increasing wages, this means an increase in production cost. This relative to the stable, almost non-increasing milk price, requires change. Now that the milk quota (maximum milk production limit) is off, farmers can produce more milk and grow their business, by means of robotised farms. (Galen, Bakker, & Beers, 2011; Hogeveen & Heemskerk, 2006; Brabantse Ontwikkelings Maatschappij, 2015)

Compared with other industries, it can be said that the agricultural industry is innovative. The innovations, both product and process related, are mainly initiated by the farmers themselves: 80 percent of product innovations and 92 percent of process innovations are initiated by the farmers. However, only 13 percent of the process initiatives are being developed by the industry self, as there is no budget for R&D (Galen, Bakker, & Beers, 2011). Amongst other initiatives, this has led to the process innovation of milking and feeding robots. These robots will replace human labour, which will not only improve the labour situation of the employees, it will also save labour costs, due to the higher efficiency, which in turn will lead to a fall in production cost. In addition, this increases the possibility for companies to grow and increase their milk production. Another advantage of robotising the milking process is the increase animal welfare. The cow can choose when and how often she is being milked. Therefore, she will she will no longer have to walk around with heavy udders (Galen, Bakker, & Beers, 2011; Hogeveen & Heemskerk, 2006).

Robot manufacturer Lely has responded to the need of this market, by developing multiple robots for the dairy industry. "On the one hand, the need for milk is growing as a result of growing population and changing eating patterns. On the other hand, we see that the cost of the livestock and especially its feed costs, which is also increasing due to scarcity. Due to the disappearance of the milk quota, milk prices will fluctuate more in the future, "explains Van der Lely (Snoo, 2012).

Reasons to invest in a robot	Number of responses	Reasons to remain a traditional farm	Number of responses
Physical labour relief	33	Investment is to high	27
Flexibility	21	Depended on robot	14
More than twice a day milking	18	Uncertainty of the reliability	8
Less employees needed	18	Hard to scale up	7
New milking system was needed	15	Second box is to expensive	7
Cow health	9	Robot does not fit in existing parlor	6
Increasing milk production	9	Other reasons	24
New stable needed	7		
It is the future	6		
Other reasons	24		
Total responses	160	Total responses	93

Table 10 Reasons of farmers to innovate or stay traditional (Hogeveen & Heemskerk, 2006, p. 12)

In 2006, Hogeveen & Heemskerk (2006), has researched the transition of a traditional milking parlor to a robotised one. According to the interviewees, labour was the main reason to purchase robots. Robots reduce the intensity of the work and also offer more flexibility. In the traditional way of milking, the farmer must milk at least twice a day at extreme times. However, there are still farmers who chose for a new traditional milking parlor, mainly for financial reasons. Purchasing a robot is still a huge investment. In Table 10, other reasons for changing to a robotic stable or not remain a traditional business are given.

According to Lely, the purchase of a robot alone is not possible. When purchasing a robot, a new business model is needed. Besides cost savings, the farmer has room to for side business, due to the increased efficiency and productivity. As a result, he will be less dependent on the milk price. The Eindhoven University confirmed that the advent of robots requires new business models in the dairy industry (LEI Wageningen UR, 2016). The biggest challenge for the dairy farm is not the use of robots, but to design a feasible business case (Brabantse Ontwikkelings Maatschappij, 2015).

7.2 Employability of the Lely robots

For this case study, farmers have been interviewed who changed their traditional farm into a robotised farm, by employing Lely robots. Lely has been working for more than two decades in the field of milking robots and automation for dairy farms. The aim of the products of Lely is to reduce labour effort of farmers. Since their establishment in 1948, they brought multiple innovative products to the market. With the innovation of the automatic milking system Lely Astronaut in 1992, the work of dairy farms changed radically. Currently, the trends within the agricultural sector are moving forward to the automation and 'big data'. They use these trends within the development of robots for the dairy farms (Lely, n.d.).

Figure 29 Lely T4C integrated management system for dairy robots (Lely, n.d., p. 23)

Nowadays, twelve products have been developed to facilitate the feeding, milking, increase the health and hygiene of the cows and pamper the cows. All these machines are connected to the Lely T4C management system. By bringing all the data together, the agricultural process will become more efficient, sustainable and profitable. Farmers can install an application which receives all the current information about their cows, the health of the cow and the animal behaviour. By means of a necklace, all the cows are monitored (Lely, n.d.).

	Purchase costs
Milking robot	€190000 - €300000
Feeding robot incl. 2 cars	€175000 - €275000
Calf feeding robot	€10000 - €15000
Manure robot	€12000 - €15000

Table 11 Prices of Lely robots given by the interviewees (Own table, base on Interviewees with dairy farms)

Robots can be purchased per unit and can be bought or leased from Lely (Lely, n.d.). The prices are including the instalment of the robot, the management system and application. In Table 11, the prices of robots according to the interviewees are shown. However, the costs do not include service costs. For a complete Lely system, as shown in Figure 29, the total service costs are around the €30000 per year (Interview Diary Farm 2).

7.3 The change in the business model of dairy farms

For this case two Dutch dairy farms have been interviewed. Both farmers used to have a traditional business, but recently purchased Lely robots. They invested in multiple milking robots, a feeding kitchen with two cars, a calf feeding machine and a manure robot. By means of interviews with the owners of the farms a traditional business model canvas and a business model canvas for the current robotised situation are designed. The detailed business model canvasses are included appendix 14.9.

In this section, all the changes within the separate buildings blocks of the business model canvas will be explained.

7.3.1 Value proposition

The production of milk is the core business of dairy farms. Since the Lely robot is a process innovation, the product has not changed after the implementation of the robots. However, the welfare of the cows improved radically, due to the increased feed intake of the cows, and the freedom of the cows to decide when and how many times a day they want to be milked. This not only increases the productivity and efficiency but also ensures a higher quality of milk. Due to robotisation the annual amount of milk produced increased, with limited workforce (Interview

Dairy farm 1 and 2). In addition, one farmer could expand his business with meeting rooms and educational events (Interview Dairy farm 1). In addition, Dairy farm 2 recognised a change in the demand for the product, while 20 years ago the focus was on the mass production of milk, nowadays there are specific market demands, such as biological milk, milk of cows which have been in the pasture (Interview Dairy fam 2). However, this shift is not caused by the implementation of the robot, but due to new trends.

7.3.2 Customer Segment

The direct customer segment has not changed over the years. Both companies deliver their milk to Friesland Campina (Interview Dairy farm 1 and 2). However, the indirect customers might have changed. Friesland Campina decides what products to produce and from which countries milk is exported. The kind of milk and farm influences this choice. However, robots by itself have not got any influences on this.

7.3.3 Customer Relationships

The relationship with Friesland Campina has not changed for both farmers. Friesland Campina consists of shares held by the dairy farms itself. Therefore, a long-term relationship is created. By means of a contract, all the dairy farms are restricted to deliver their milk only to Friesland Campina. Because the farmers themselves have shares in the Friesland Campina, they financially benefit from the revenues of Friesland Campina. Due to their share, they also have (limited) influence on this corporation, by means of general members meeting. This relationship remained unchanged after the robotisation (Interview Dairy farm 1 and 2).

7.3.4 Channels

Since the customer segment and relationship remained, also the channels are unchanged. Both dairy farms (Interview Dairy farm 1 and 2) deliver their product to Friesland Campina, which is a corporation. Therefore, the channel is business to business. They deliver indirectly their product to the final customer.

7.3.5 Key Activities

Key activities have drastically changed due to robotisation. In the traditional farm, the farmer and its employees produced between 130 - 153 litres an hour. They executed jobs such as feeding the cows, bringing the cows to the milking machine, cleaning the utensils, place the milking bowls and manuring. These heavy physical jobs are replaced by robots. Therefore, the activities of the farmer and its employees have shifted to mainly monitoring the entire business; this is done by means of an application, which merge and analyse all the gathered data from the robots. In both companies, robots are taking care of the whole milking process, robots are used to bring and prepare the food and the manure is also automatically done. Hence, the productivity has at least doubled. In the case of dairy farm 2, this has even increased in six-fold.

7.3.6 Key Resources

The change in activities is caused by the purchase of robots. These robots are part of the key resources of the farms. Since these robots are partly replacing old equipment, some traditional equipment will be discarded. In addition, both farms decided to outsource all the agricultural activities. However, dairy farm 2 still has the traditional equipment for these activities. Furthermore, a shift happened in the human resources of both dairy farms. In Dairy farm 1, the same number of workforce is hired. However, higher educated personnel is required in order to work with the robots. In dairy farm 2, the labour hours are halved. Due to the robots, more cows can be held; both farms doubled the number of dairy cows. Therefore, the production of milk increased. In order to implement robots, both farms needed a new milking parlor.

7.3.7 Key Partners

In general, a dairy farm has the following partners: Accountant/Business advisor, Agrifirm (Feed operation), Equipment services, Food advisors, Veterinarian. Due to the Lely robots additional equipment are not needed. Lely will not just deliver the robots but will have a service contract with the purchaser. Therefore, Lely became a new partner. In addition, over the years the agricultural work is outsourced to external employees. These workers are only needed at peak times. Therefore, it is better to spend this work (Interview Dairy farm 1).

7.3.8 Cost Structure

The milk industry is a cost-driven industry. They are always steering towards the lowest production cost. In the traditional farm, the production costs per litre of milk were less than 31 cents. This included the mortgage of the farm and equipment, labour costs and service costs for the equipment (Interview Dairy farm 1 and 2). However, in the new situation, this remains the same (Interview Dairy farm 1) or even slightly increased (Dairy farm 2). This is caused by the high investment costs (increasing mortgage) of the robots and milking parlor. Both companies decided to buy the robots instead of lease. Also, the service costs of Lely are much higher than the traditional equipment costs. However, for company 2, the labour costs decreased radically 3 to 4 cents per litre milk. This total means a decrease of €70000 of labour costs a year (Interview Dairy farm 2).

7.3.9 Revenue streams

The revenue of the dairy farms is two-fold. First of all, the revenue of the milk. The milk prices have increased during the last 20 years, starting with 32 cents per litre to nowadays 36/40,5 cent per litre, based on the contract with Friesland Campina. Since the number of produced litres of milk a year, has in both cases at least doubled, the total profit of the dairy farms has significantly increased. Of course, this was not a surprise for both companies, they both calculated a complete business case to make sure that they will have a return on their investment. Amongst others, they calculated the break-even point, in which they determined how many cows were needed to make this investment profitable This was also needed in order to get a mortgage at the bank. Secondly, both companies have a share in Friesland, of which they receive a yearly profit (Interview Dairy 1 and 2).

7.4 Advantages and disadvantages of Lely Robots

There are several reasons why robots are beneficial in the dairy industry. First of all, it increases flexibility and reduces the human labour, which is experienced as physically heavy. A shortage of workers and the increased wages makes a robot beneficial in this industry. Due to the feeding robot, the intake of food per cow will increase, this positively influences the milk production with 0,5 litres per cow a day. In addition, it reduces the amount of waste feed with 75 percent and on the feeding activities itself, 29 minutes a day is saved, due to the feeding robot (Lely, n.d.). Besides the fact that Lely robots thus decrease the costs price of milk, it also improves the health conditions of the cow. The cow, herself can decide when and how many times a day she will be milked (Hogeveen & Heemskerk, 2006; Galen, Bakker, & Beers, 2011). In addition, the use of technology generates data. Therefore, information about the production of milk and the welfare of cows is always updated and available by means of an application.

However, the investment costs of robots are high (Hogeveen & Heemskerk, 2006). This deters farmers to purchase a robot. In addition, the fact that a farmer has to solve robot issues 24 hours a day is seen as major disadvantages.

7.5 Conclusion

This chapter serves as inspiration for the customized business model for construction companies. It examines how the business models of dairy farms have changed through the implementation of robots. In order to analyse this, two farmers were interviewed who recently purchased robots. During the interview, the current and traditional business models were discussed. Both situations are illustrated in the business model canvas to analyse where the biggest differences took place.

First of all, robotisation in the dairy industry is a process innovation; the product remains unchanged. However, the production and efficiency increased, less employees are needed and the cow welfare grew. In addition, this new technology produces and analyse data, which makes it easy for the farmer to manage the farm. The customer segment, relationship and channels do not change, Friesland Campina is the only customer of these dairy farms. Significant changes took place in the building block key activities. Here it becomes clear that the physical labour of the farmer is taken over by robots. In case of Dairy Farm 1, this means that there was room for additional business. The productivity of the companies has also increased significantly. This is at least doubled (Dairy farm 1) or is even six-fold. Where the farmer and his staff were initially responsible for physical work, they shifted towards are more management role, in which they analyse the data gathered by the robots, by means of the Lely application. Due to the advent of different robots and the application, the key resources have changed. As a result, with the same number of workforce, more milk cows can be held (Company 1), or with the same number of cows, fewer employees are needed. In both cases, less manure is required to produce a litre of milk. To enable robots, in both cases a modified milking parlor had to be built. In the building block Key Partners, a new service partner is added. Lely is not just the seller of the robots, but will also be a service partner. The changes in activities, resources and partners have caused a shift in the cost structure. The cost of the mortgage (equipment) and service has risen, on the other hand, it can be said that labour costs have fallen. At Dairy farm 2, the difference in labour costs is extreme; they save 3 to 4 cents per litre of milk. Over the years, the milk price has barely increased. However, the overall revenue has risen sharply, as productivity has increased. To make sure total revenue would grow, they have calculated the entire business case to find out what the break-even point of this investment was.

8 3D CONCRETE PRINTING ROBOT

In this chapter, the chosen robot, a 3D concrete printing robot is explained. First, a small introduction about several 3D printing techniques and its state of the art is given. Second, features of the chosen robot are described. The chapter concludes with the benefits of 3D printing.

8.1 Introduction of the 3D concrete printing robot

The development of 3D printing or additive manufacturing is going extremely fast. Currently, 3D printers can print plastics, paper, aluminium, titanium, stainless steel, silver, gold, bronze, ceramic and concrete (Deursen, 2016, p. 13). The last one is interesting for the construction industry. Over the years several companies, start-ups, but also universities have been focusing on 3D concrete printing. In general, three types of 3D printers can be classified.

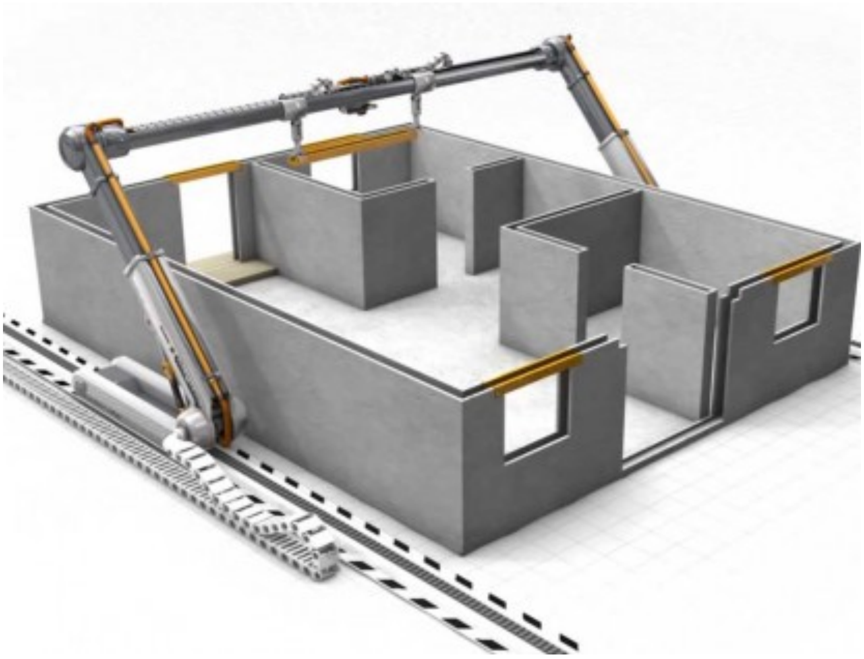


Figure 30 Winsun 3D printing construction research (Pilot Design, n.d.)

First, 3D printers that operate on an overhead crane. These 3D printers are especially suitable for printing under controlled conditions since it takes a lot of time installing them. The University of Eindhoven, Loughborough and Southern California work on these developments, although with minor differences. Most famous producer of houses manufactured in this way is Winsun, a Chinese company. In 2014, they produced their first homes, for only 4200 euros. The houses that are built with concrete made of waste materials can be manufactured within a day (Deursen, 2016).

Figure 31 Mobile 3D printer of Apis Cor (Apis Core, 2017)

Secondly, there are mobile robots. An example of this kind of robot is the Cybe and Apis Cor printer. Both companies work with a mobile 3D concrete print robot. The Apis core printer is attached to a tower crane, which rotates about an axis. Therefore, the printer always has to be in the middle of the building to be printed. The Cybe printer consists of a robot from the automotive factory, where a nozzle for 3D printing is attached (Deursen, 2016).

The last category of 3D printers, consists of small mobile robots on which nozzles are attached. An example of this is IAAC mini builders. Three different robots perform a different task, in order to print a building together. In addition, research on 3D printing with a drone is currently being conducted (Deursen, 2016).

Figure 32 Cybe 3D concrete printing robot on the construction site in Dubai © Cybe

Although in the Netherlands a lot of experiments have been done, amongst others by the Technical University of Eindhoven and the start-up Cybe, no real-life case have been constructed yet on Dutch ground. However, last spring Cybe released its first assignment in Dubai, where they built a drone lab through 3D-printed concrete elements. Currently, they are working on their second construction project 'De droomfabriek'. This will be the first 3D concrete printed building of Europe. Since Cybe is the only Dutch construction company focused on mobile 3D concrete printing, this company is taken as an example for this research thesis. All the information and calculations are based on their specifications.

8.2 Features of the 3D concrete printing robot

The Cybe 3D concrete printing robot is developed to construct houses. At this moment, the Cybe printer is able to print elements of outer and inner walls for housing, with a height up to 3,5 meter. However, the development of housing takes quite long, since buildings need to meet the standard regulations. Therefore, Cybe expanded their market. Currently amongst others frameworks, sewer pits, abutments and floors can be produced by this robot (Cybe, n.d.).

In order to print elements, Cybe developed a hardware, software and material. The hardware consists of a mobile manipulator, mix-pump system and a control unit with an interface. By means of a caterpillar, the robot becomes mobile. The hardware is driven by two kinds of software programs Cybe Chysel and Cybe blueprint. This program translates parametric designs into orders for the robot. This software can simply be connected with Rhino. In addition to the hardware and software, fast drying cement has been developed. According to Vaessen (2017), the nozzle of the robot can only print with this specifically developed cement. For the construction a construction tent, water supply, electricity and LAN is needed to construct (Cybe, n.d.).

Currently, Witteveen & Bos has been calculated the construction produced by the 3D concrete printer. The current construction meets the Dutch Regulations. However, in order to ensure the tensile strength, reinforcement will manually be applied in the wet construction (Vaessen, 2017).

	Number	Unit
Construction time	200	mm/s
Lifespan	10	years
Maintenance/service costs	€35000	year
Operational workforce	2	employees per robot
Price Mortar	€21500	dwelling
Robot (rent)	€800	day
Robot (sale)	€350000	robot
Total price as sub-contractor	€41750	dwelling

Table 12 Features of the Cybe 3D concrete printing robot (Own table based on the numbers of Cybe)

In the table above the current prices are shown. When purchasing a robot, the software will be included. However, the cement Cybe Mortar must be purchased per project. For this thesis Cybe calculated the amount of Mortar needed, as well as the total contracting price, the total price for which Cybe will built as a sub-contractor. In appendix 14.10, the cost calculations and price offer is included. In order to operate the robot on-site a tent and WIFI are needed on location, as well as power. In addition, when the in-hour constructor is not able to calculate the construction an external contractor should be hired. The costs of these last amenities and service is not taken into account.

	Casting	Masonry	Wooden skeleton	Prefab elements	Prefab units	3D printing
Preparation time	Medium	Short	Long	Long	Long	Short
Construction site	Big	Medium	Small	Small	Small	Small
Construction time	Medium	Long	Short	Super Short	Super short	Medium
Consumer-oriented	Low	High	Low	Medium	Medium	Super high
Equipment cost	Super high	Low	Low	High	High	High
Finishing	High	Low	Low	High	Super high	High
Labour intensity	Low	Super high	Medium	Low	Very low	Low
Scale of the project	Big	Small, variation	Small	Big	Big	Small
Weather dependency	Super high	Medium	Low	Low	Low	Low

Table 13 Construction methods for row houses (Own table, based on Bongers, 2007; Cybe, n.d.)

In Table 12 the different construction methods are illustrated, including 3D concrete printing. Compared with the existing methods, it can be state that 3D printing makes a higher level of consumer-oriented production possible. Till the day of construction small adjustments can be made. Since the robot can print directly from a BIM file, the preparation time is short, even shorter than the traditional way of constructing, since the software also includes construction measurements. The 3D printed elements are printed on location, since the printers are not that big, a construction tent can cover the part of the construction site, where the printer is running. Therefore, the printer is independent of the weather. The printer can be operated with two men, however piping, plastering and wiring should be done manually. The purchase and rent of a robot, compared with other methods is expensive (Cybe, n.d.).

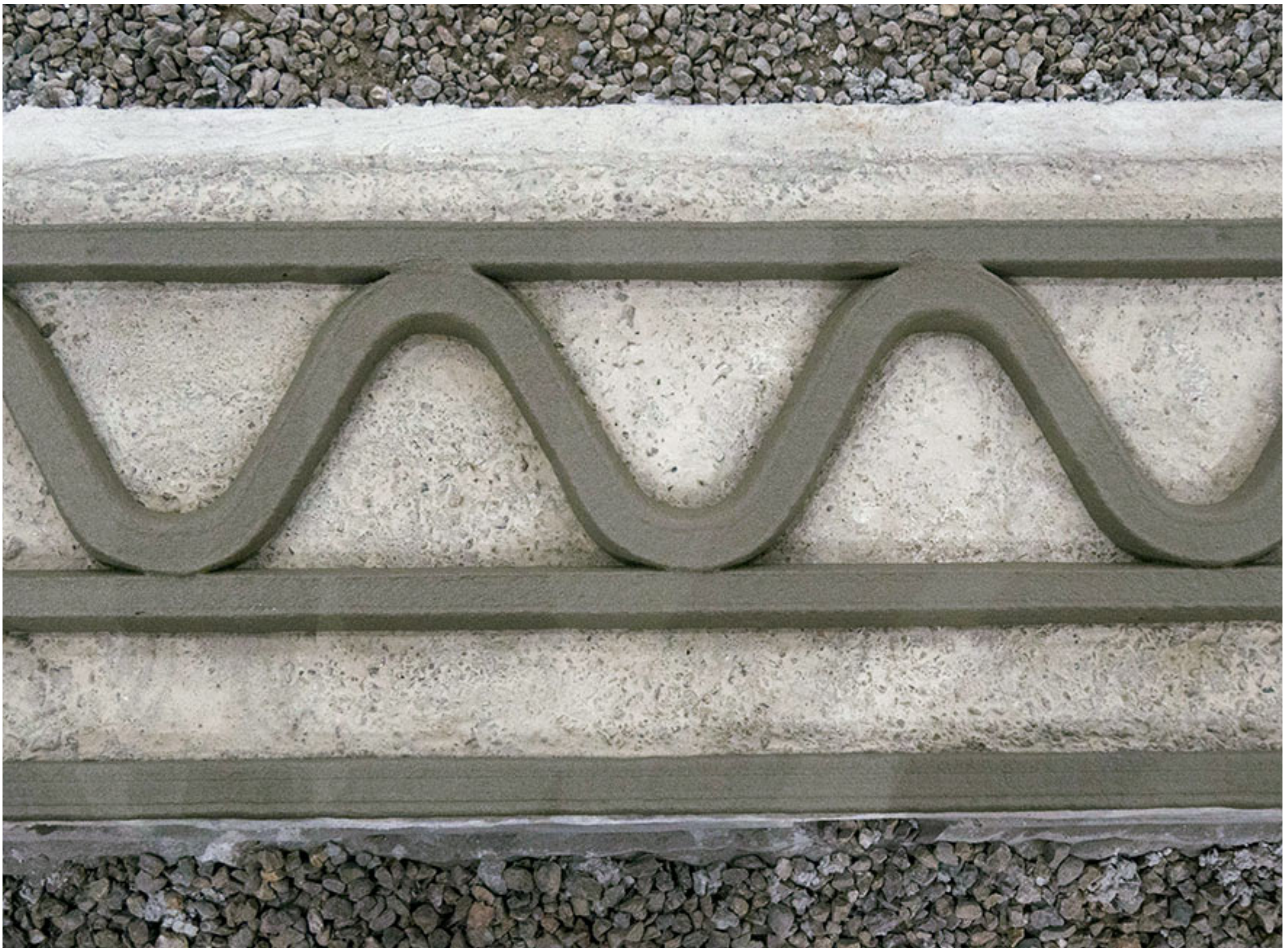
8.3 Advantages and disadvantages of 3D concrete printing

There are several advantages of printing instead of constructing. First of all, the Cybe printer claims to build 200 mm per second, which is faster than a traditional construction project. The sustainability increases, due to the hollow construction less material is needed. This enables construction with thinner wall packages by integrating the insulation into the printed wall structure. In addition, on-site construction will diminish transport costs and thus CO_2. Furthermore, fewer workforce is needed, only two employees are needed to construct walls. This response to the shortage of construction workers. In addition, the heavy physical tasks are performed by robots. Thereby, it is said that the construction with a 3D printer is cheaper than the traditional methods. Last, the possibility to print highly complex buildings, which are not possible or expensive to build with traditional methods. (Cybe, n.d.)

Currently, a lot of actions has to be done by hand, such as the reinforcement, plastering and moving the device. However, this also bring opportunities with it. It is possible to integrated pipes and wires, during the construction process, this might decrease the total construction time of a building (Vaessen, 2017).

8.4 Conclusion

For this research thesis, the Cybe 3D concrete printing robot has been chosen; this robot produces concrete elements on the construction site. Only two construction workers are needed to operate the robot and construct walls. Cybe developed three products, which together are able to amongst others construct several kinds of frameworks and walls. The first product is the hardware; a concrete nozzle is attached to a mobile automotive factory robot, which can be driven by an interface and is attached to a mix-pump system. Second, software programs have been developed to drive the manipulator. Last, Cybe developed its own fast-drying cement, Cybe Mortar. Since the robot is placed on a caterpillar, heights until 4,5-meter height can be reached. However, when a larger caterpillar is used, even higher elements can be produced. The 3D printed construction has been investigated by Witteveen and Bos, according to their measurements, the elements meet the Dutch construction regulations. However, the placement of reinforcement, wiring and piping should be done manually when the cement is still wet. The use of a 3D concrete printing robot compared to the existing ways of construction is beneficial in terms of, productivity and efficiency, decreases the construction time and construction costs. In addition, this construction method can produce complex forms for low costs and adjustments in the design can easily be made.



E SYNTHESIS & DESIGN

9 ADJUSTED BUSINESS MODEL FOR CONSTRUCTION COMPANIES

This chapter combines all the gained knowledge. With the current business model as the basis and inspiration of the changed business models of dairy farms and the input of the chosen robot, a proposal will be made for an adjusted business model. This is validated by means of a focus group. The derived knowledge of this focus group is the input for the final business model. This chapter answers the question: 'How will individual aspects of the currently used business model of construction companies change due to the use of robots?'

9.1 Synthesis of input for the adjusted business model

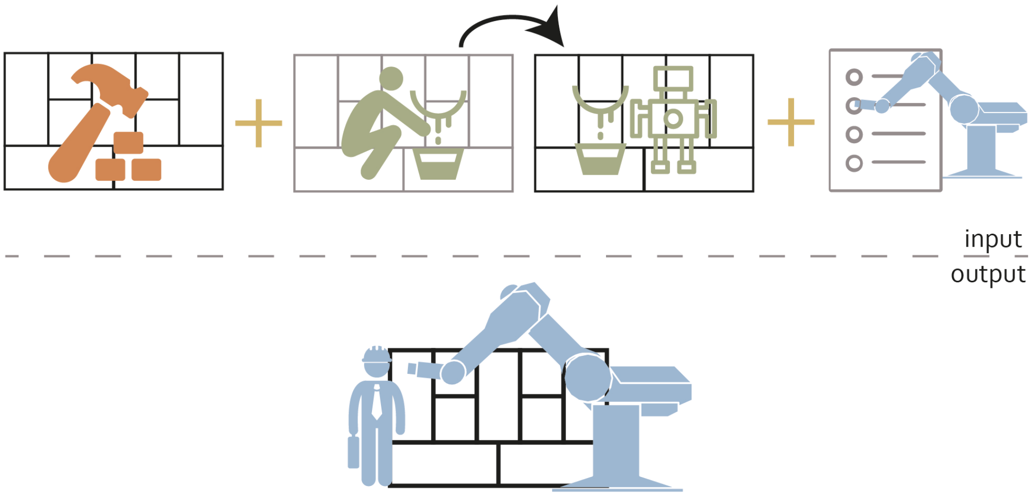


Figure 33 First design phase (Own image)

There are three different sources of data used as input for the adjusted business model of construction companies to make on-site robots possible: the current business model of construction companies, the changes which occurred in the business model of dairy farms and the features of the chosen robot.

9.1.1 Input of the current business models

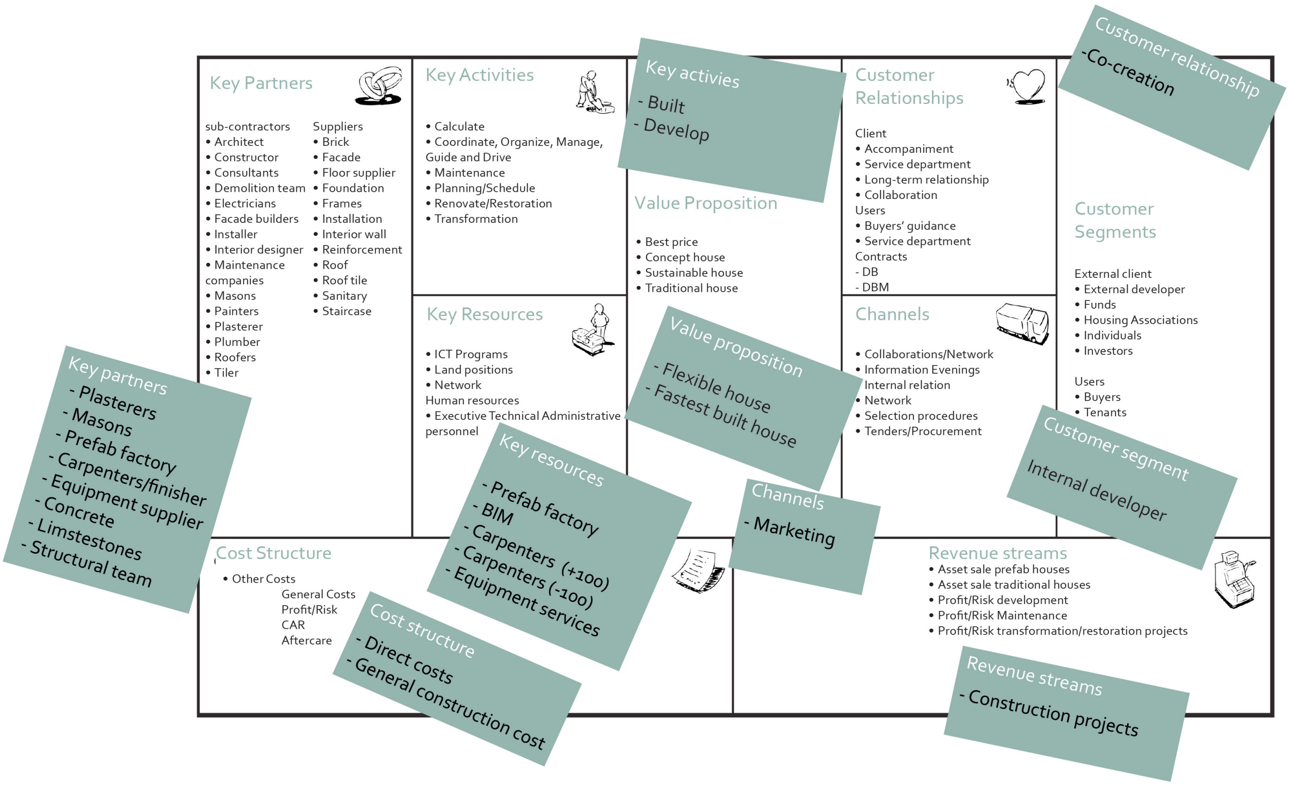


Figure 34 Synthesis of the current business model (Own image)

First of all, the current business model of construction companies will be used as the basis of the adjusted business model. Based on the business model canvasses composed for the construction companies, it can be concluded that it is not possible to create a generic business model. Therefore, all the possible elements are combined into one merged business model. In this model, there are some elements which in general remain at the same position. These elements are not expected to change when implementing a robot. Besides, there are some elements which; switch between buildings blocks, are not present in all the business models but are expected to be important or elements of which the quantity is expected to change. These are added in the coloured boxes of Figure 34. All the black elements are expected to be standard or are assumed not important for the changing business model.

9.1.2 Input of other industries

Robots in the dairy farms solved similar problems as in the construction industry; a shortage of workforce, increasing wages and heavy labour. Due to the implementation of robots, productivity increased, which resulted in a highly-increased revenue.

The robotisation in the dairy farms has changed several aspects in the business model. However, it is important to take into account, that the innovation in the dairy industry was just a process innovation, while robots in the construction will also have influence on the product itself. The following of these changes might also be applicable to the adjusted business models for construction companies:

- The key resources are changed due to the purchase of robots. In addition, because robots are taking over human labour, fewer and a different type employees are needed. The employees which remain should have knowledge about the robot software and application. Due to the increased productivity, more cows can be held.
- The key activities radically changed. The farmer almost becomes a manager of data instead of a farmer. Robots are taking over the heavy and labour intensive activities and are thus replacing human workforce.
- The robot requires an additional key partner, to maintain the robot and update the software.

- Due to the increase equipment costs, the production costs have not been reduced, but the labour costs drastically reduced.
- The revenue streams have highly increased due to the higher productivity. Therefore, this innovation became feasible.
- Higher quality of the product is achieved due to robotisation.
- Increased flexibility, no longer restricted to specific times.

9.1.3 Input of the chosen robot

The following information collected during explorative interviews and from available online sources about 3D printing has been used as input for the design:

- The robot will print only inner and outer walls.
- The 3D concrete printing robot is a faster construction method than the traditional one, with a speed of 200 mm per second. Reduction of production time by 75 percent.
- The cost of a robot:
    - Rent per day €800
    - Purchase of the robot €350000 + €35000 service costs per year
    - Mortar price per row-house €21500
    - Cybe as sub-contractor (everything included) €41750
- Lower production cost, because less material and transportation needed
- Decreasing labour costs, only two employees needed to operate the robot. Heavy physical work is executed by the robot.
- Better for the environment, fewer emissions and material needed.
- Increased flexibility of the design (also in a later stadium).
- Decreased preparation time is needed.
- Independent on the weather, when printing in a tent.

9.2 Adjusted business model for construction companies

The current business model, the inspiration from the case study and the features of the robot has led to the following proposed changes in the existing business model. The costs calculations in this model are based on assumption, since the exact numbers at this stadium of the research where unknown.

At the first draft, the robot is placed in the own key resources. At this location, the robot will have the biggest impact on the business model. When placed at the key partner, the impact is minimal. The complete business model is illustrated in Figure 35. Elements on which the robot will have a positive influence are marked yellow. The light grey ones disappear or decrease.

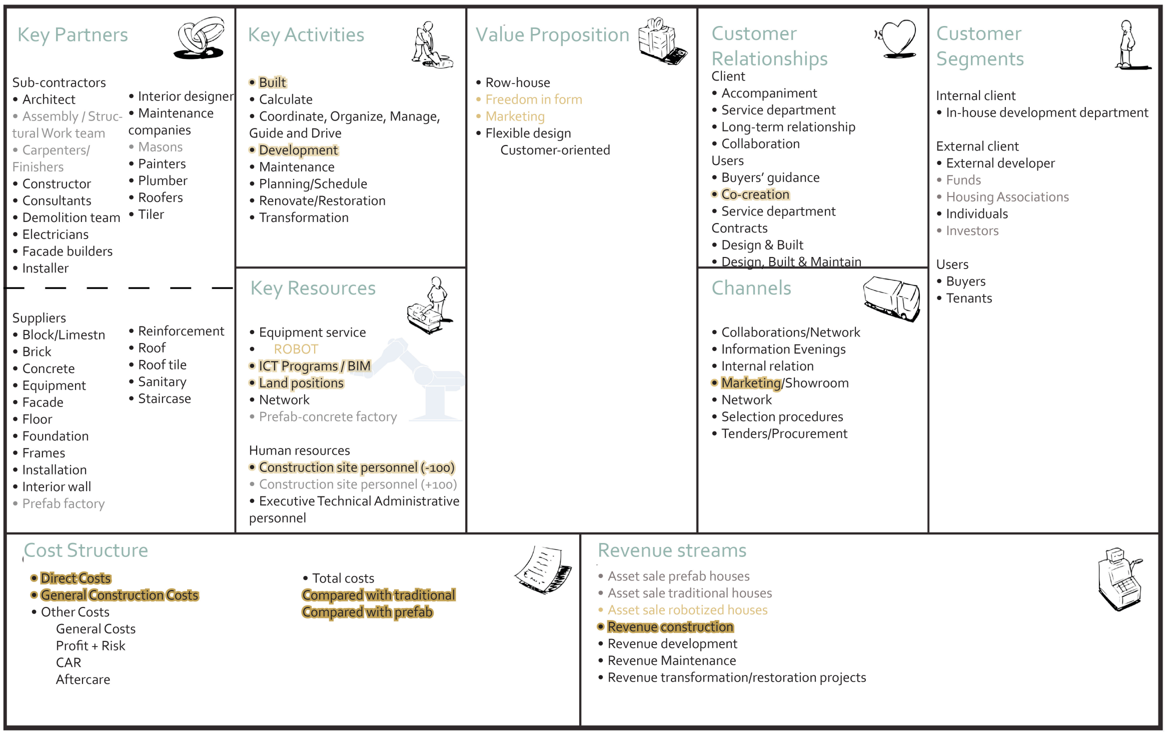


Figure 35 Adjusted business model first draft (Own image)

Value proposition

The product will be unchanged; still a row-house will be produced. However, there is a possibility to create highly complex forms, which makes this type of construction valuable for customer-oriented design. This can also be used as a marketing strategy. In addition, the sustainability increases, which also adds value to the product.

Customer segment

The customer segment remains the same since the final product is still a row-house. However, this custom designed product is more suitable for sale houses, and therefore initiators such as developers will have more benefit from this construction method.

Customer relationship

The customer relationship remains the same. However, since the flexibility increases and a higher level of customer-oriented design is possible. Therefore, co-creation becomes more intense.

Channels

In addition to the current business model, the robotised housing can be used as a marketing strategy because this is unique at the moment in the Netherlands.

Key activities

Since the construction companies will operate the robots themselves, the share in the construction process will increase. New operations will be carried out by the construction company itself.

Key resources

The robot will be purchased by the material service. Therefore, having a material service is crucial. The implementation is expected to be more urgent for companies with only a few in-house carpenters, as the scarcity of workforce will be noticeable earlier. Construction companies with an own prefab factory will use the prefab factory less efficiently due to the arrival of the robot. Therefore, companies without a prefab factory will earlier implement robots.

Key partners

In general, there will be one new key partners, the maintenance and service company for the robots. In addition, less external carpenters are needed since robotised companies require fewer employees. The masons are not needed for limestone wall construction anymore. In case a construction company purchase products of an external prefab factory, fewer products will be purchased.

Cost structure

The implementation of a robot is expected to decrease the total construction cost. According to Cybe, the 3D concrete printing robot developer, a saving of 20 percent on the construction costs is possible. Besides, labour costs decrease as fewer carpenters are needed. However, the material and equipment costs will increase due to the purchase of the robot and the expensive production material, the cement. Last, transport and material costs will decrease.

Revenue streams

The increased productivity and own share in the construction process will increase revenue stream.

9.3 Validation of the adjusted business model

Figure 36 Internal validation by a focus group (Own image)

The first drafts of business models are internally validated by means of a focus group consisting of four professionals of Dutch construction companies. The purpose of the focus group is twofold. First of all, the focus group is organised to get input for the business model. Secondly, this focus group will validate the first draft. The participating companies were also interviewed for the current business model. Except for one person, all participants were familiar with the research. Prior to the meeting, all participants received a document containing a brief explanation of the focus group's purpose, the business model canvas that will be used and a short description of the robot to be implemented: the 3D concrete printing robot. Before the participants started with the brainstorm, a brief introduction was given about the program of the focus group and the research itself. The invitation is added in appendix 14.12.

The program of this meeting can be divided into three parts. In the first part, the participants get started with a brainstorm session about the best place to implement robots within existing business models. This will provide information as input for the model. In the middle of the focus group, a spontaneous session started, where a completely new business model was created. The focus group was concluded with discussing the adjusted business model designed by the graduate student, in order to internally validate the model.

9.3.1 Output of the focus group

Based on the information retrieved during the focus group, three strategies could be thought of in which the robot is implemented:

- as a sub-contractor in the key partner building block;
- as an external equipment services (supplier) also in the key partner block;
- as internal equipment in the key resources of the company self.

In addition, the following points are taken into account, while designing the final business model:

- Elements such as having an own prefab factory or a lot of own carpenters will not negatively influence the motivation of implementing a robot. However, lacking an own prefab factory and fewer internal construction personnel will increase the need and thus the increase the motivation of implementing a robot.
- Individuals who demand a special design are a suitable target group
- If the construction company has to operate the robot themselves, extra knowledge and ICT programs will be needed.
- The operation of the robot needs additional knowledge. Therefore, courses should be organised to re-educated the employees or new personnel should be hired.
- Construction companies need to be convinced by numbers. Therefore, a traditional project will be compared with an assumption of a robotised project, in terms of costs and construction duration.
- Small nuances in the business model are important. Therefore, a combined business model including all the possible elements will be used as the basis, so that all the nuances are included. Only the changing elements are highlighted.

9.4 Final business models

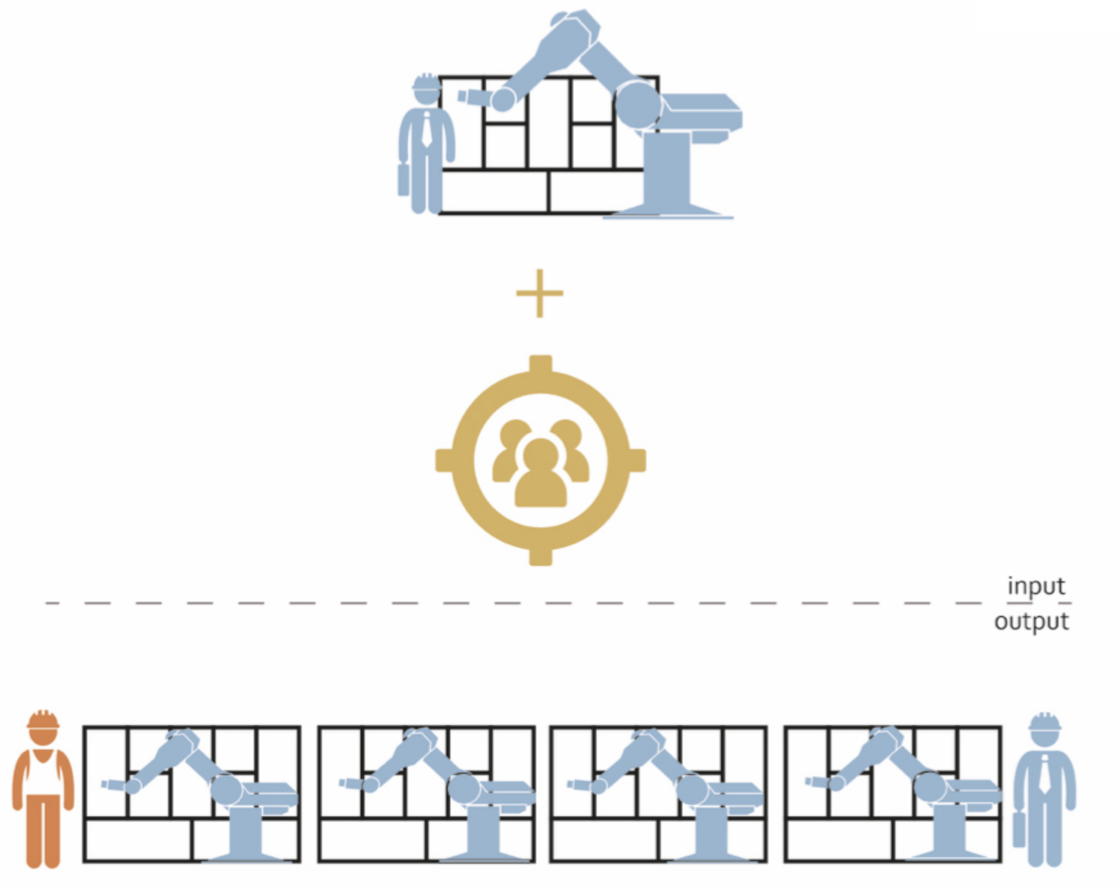


Figure 37 Second design phase (Own image)

Although this research started with the aim to design one generic adjusted business model for construction companies to make on-site robots possible, this turned out to be impossible. This is also confirmed by the focus group. In this section, all the possible strategies to implement a robot are expressed.

9.4.1 Strategy 1: Sub-contractor model

In the first strategy, the robot will be implemented as a sub-contractor in the building block of the key partners.

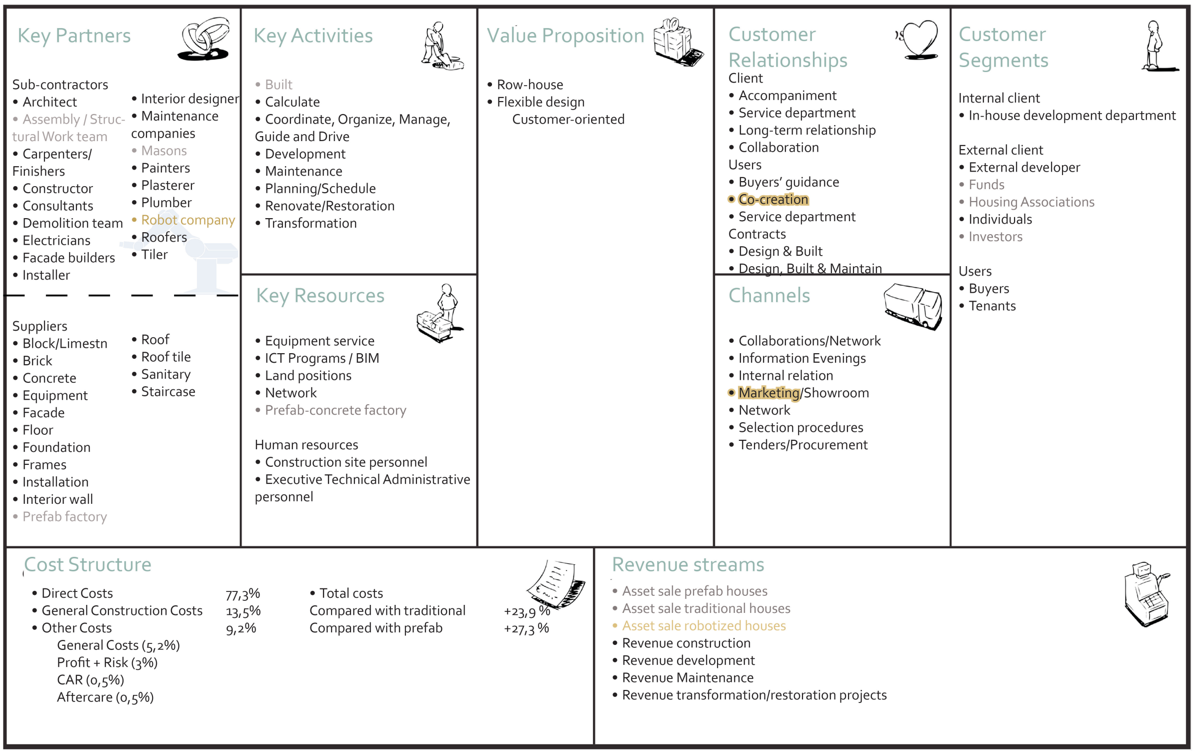


Figure 38 Business model strategy 1 (Own image)

Value proposition

Row-houses are still the main product of construction companies. However, due to the implementation of robots, the design becomes more flexible and will be highly customer oriented. Therefore, robots are not only seen as process but also product innovation. Even just before printing customers can adjust the design because the preparation time is shorter than in a traditional construction process. Less transportation and materials are needed, and therefore the 3D printed house will be more sustainable. Of course, the printer can also be used for 'standard' design. However, it will be most profitable to use it for the customer made, unique designs. Since the robot will be purchased by an external party, the construction company is still flexible and can choose by a standard design for prefab or the traditional construction method.

Customer segment

The customer segment will remain the same. Construction companies for internal development department, the external developer, funds, housing associations, individual and investors. The 3D concrete printing robot will be most valuable for construction projects of owner-occupied houses since the design can be adjusted to the buyers' preferences. This construction method is therefore especially suitable for individual customers and internal developers. Funds, housing associations and investors mainly build rental properties, which should be suitable for different types of residents.

Customer relationship

Small changes can occur in the customer relationship, due to the possibilities with the 3D concrete printing robot. When the robot is used for a customer-oriented design, the co-creation between the clients and construction company will become more intense than in case of the small variations possible with the traditional or prefab construction method. The contract types will remain.

Channels

Construction companies have different ways of approaching customers and acquire jobs. This will not change in general. However, a 3D printed house might be good for the marketing.

Key activities

The key activities of the construction company will remain the same as in the traditional or prefab situation. Since the sub-contractor will execute the job with the 3D concrete printing robot, the construction companies share in the building process remains the same. Only the inner and outer walls are produced differently, compared to the traditional situation.

Key resources

Depending on the specific construction company, the key resources of the construction company remains unchanged. The robot will be purchased by a partner; therefore no additional personnel is needed. In general, the assembly and construction activities are executed by an external party. When own employees are executing these activities, it might decrease the need of own carpenters. However, the construction of the walls is only a small part of the total construction process and will thus minimally influence the need for construction workers. When the construction company owns a prefab factory, the factory might slowly take off in production. However, prefab floors are still needed. In addition, the construction company itself is not investing in the robot, which makes them flexible in choosing a construction method, because they do not need to get a return on this investment.

Key partners

A new sub-contractor will be added to the key partners, who will execute the inner and outer wall construction and will bring all the materials and (almost) all the equipment. Depending on the specific construction company less external assembly workers are needed, because the new sub-contractor will be responsible for an own operation team and less workforce is needed to construct the walls. This is beneficial in the time of scarcity of construction workers, since they are less dependent on construction workers. Also, the need for masons will decrease, they will no longer be needed for the construction of walls, only for the brick façade. In addition, a tent should be rented from an external equipment party and in case of an external prefab factory, the production will slow down, only floors will be purchased.

Cost structure

		Traditional project	Prefab project	Strategy 1
Total price difference		100 %	97,3%	123,9 %
Direct costs	Labour	8,2%	5,4%	6,1%
	Material	17,5%	11,6%	12,1%
	Equipment	0,9%	0,3%	1,8%
	Sub-contracting	47,5%	61,1%	57,2%
General construction site costs		16,7%	12,5%	13,5%
Other costs		9,2 %	9,2 %	9,2 %

Table 14 Relative cost structure strategy 1 (Based on the numbers of Heijmans and own calculations)

The total construction costs will increase by 23,9 percent compared with the traditional construction method and will be 27,3 percent more expensive than prefab. This has to do with the increase in direct costs. The fee for the sub-contractor of €41750 is higher than the traditional construction cost of the walls. The cost ratio shifts, due to the new sub-contractor the sub-contracting item increases compared to the traditional situation. However, since the new sub-contractor will only be responsible for the construction of the walls, the sub-contracting item is less than the prefab situation, in which the whole shell is produced by a sub-contracting party. Own labour and material decrease, since this is included in the sub-contracting sum. The equipment increases since a construction tent is needed. The general construction site costs remain the same as in the traditional situation, but due to the increased direct costs, the share of the general construction site costs decreases. An important note, the construction of the walls will happen on-site but within a tent. Therefore, this construction method is less independent and thus increasing cost due to weather delay can be prevented. The share of the other costs remains the same for all the strategies. The total cost calculation can be found in appendix 14.10.

Revenue streams

The total revenue will be unchanged because the construction company will not have a bigger share in the overall construction activities. Only an extra category will be added; the asset sale of robotised houses.

9.4.2 Strategy 2: Equipment supplier model

For the second strategy, the robot will be rented from an external equipment party (supplier) in the building block of the key partners.

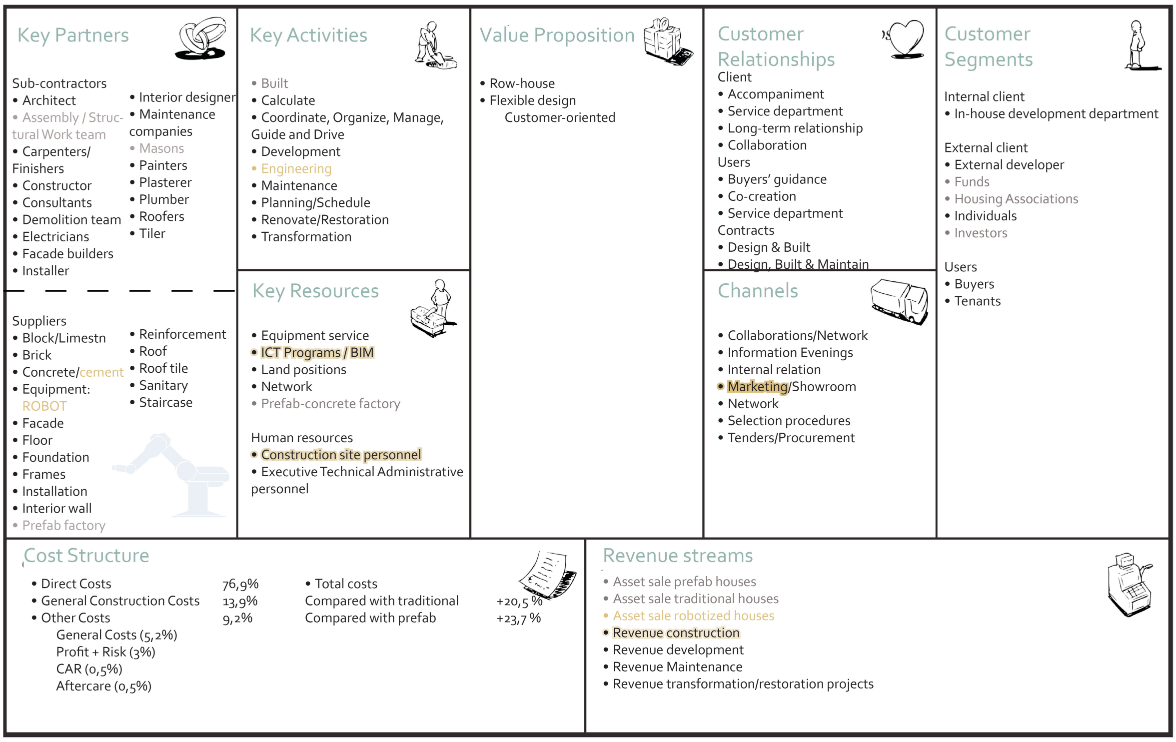


Figure 39 Business model strategy 2 (own image)

Value proposition

Row-houses are still the main product of construction companies. However, due to the implementation of robots, the design becomes more flexible and will be highly customer oriented. Therefore, robots are not only seen as process but also product innovation. Even just before printing customers can adjust the design because the preparation time is shorter than in a traditional construction process. Less transportation and materials are needed, and therefore the 3D printed house will be more sustainable. Of course, the printer can also be used for 'standard' design. However, it will be most profitable to use it for the customer made, unique designs. Since the robot will be purchased by an external party, the construction company is still flexible and can choose by a standard design for prefab or the traditional construction method.

Customer segment

The customer segment will remain the same. Construction companies for internal development department, the external developer, funds, housing associations, individual and investors. The 3D concrete printing robot will be most valuable for construction projects of owner-occupied houses since the design can be adjusted to the buyers' preferences. This construction method is therefore especially suitable for individual customers and internal developers. Funds, housing associations and investors mainly build rental properties, which should be suitable for different types of residents.

Customer relationship

Small changes can occur in the customer relationship, due to the possibilities with the 3D concrete printing robot. When the robot is used for a customer-oriented design, the co-creation between the clients and construction company will become more intense than in case of the small variations possible with the traditional or prefab construction method. The contract types will remain.

Channels

Construction companies have different ways of approaching customers and acquire jobs. This will not change in general. However, a 3D printed house might be good for the marketing.

Key activities

The key activities changes, since the construction company is just hiring a robot, they have to operate the robots themselves. Therefore, their share in the construction process will increase. In addition, they need to engineer the design and prepare the design for the 3D concrete printing robot.

Key resources

In this strategy, the key resources of construction companies will slightly change. The robot will be rented from a partner, but the engineering and operation will be done internally. Therefore, new ICT programs are needed, and personnel should be trained or newly hired to operate the robot. However, the construction of the walls is only a small part of the total construction process and will thus minimally influence the human resources. When the construction company owns a prefab factory, the factory might slowly take off in production. However, prefab floors are still needed. In addition, the construction company itself is not investing in the robot, which makes them flexible in choosing a construction method, because they do not need to get a return on this investment.

Key partners

A new supplier will be added to the key partners, who will rent the robot to the construction company. To construct the walls with the 3D concrete printing robot, cement and reinforcement need to be purchased from a new supplier. Also, a tent should be rented from an external equipment party. In case of an external prefab factory, the production will slow down; only floors will be purchased. Depending on the specific construction company less external assembly workers are needed to construct the shell, because only two (in-house) employees will operate the robot. The need for masons will also decrease, they are only needed for the brick façade. This is beneficial since the scarcity of construction workers will grow the upcoming years. In case of an external prefab factory, the production will slow down; only floors will be purchased.

Cost structure

		Traditional project	Prefab project	Strategy 2
Total price difference		100 %	97,3%	120,4 %
Direct costs	Labour	8,2%	5,4%	9,8 %
	Material	17,5%	11,6%	12,7 %
	Equipment	0,9%	0,3%	1,9 %
	Sub-contracting	47,5%	61,1%	52,6 %
General construction site costs		16,7%	12,5%	13,9%
Other costs		9,2 %	9,2 %	9,2 %

Table 15 Relative cost structure strategy 2 (Based on the numbers of Heijmans and own calculations)

The total construction costs will increase by 20,4 percent compared with the traditional construction method and will be 23,7 percent more expensive than prefab. This has to do with the increase in direct costs. Both the rental cost of the robot and cost for the cement is purchased from one supplier; these costs are included in the sub-contracting item of the direct costs. Since in this strategy, own employees will operate the robot, labour costs increased. Compared to the traditional construction method, the equipment increases since a construction tent is needed. The general construction site costs remain the same as in the traditional situation, but due to the increased direct costs, the share of the general construction site costs decreases. An important note, the construction of the walls will happen on-site but within a tent. Therefore, this construction method is less independent and thus increasing cost due to weather delay can be prevented. The share of the other costs remains the same for all the strategies. The total cost calculation can be found appendix 14.10.

Revenue streams

The revenue streams slightly increase. The robotised houses will get a share in the asset sale. Since the construction company will have a bigger share in the overall construction activities, the revenue of construction will slightly increase.

9.4.3 Strategy 3: Robotised contractor model, worst-case scenario

For the third strategy, the robot will be purchased by the equipment department of the construction company itself, and will thus be part of the key resources of the company. For this strategy, two scenarios are designed: a worst and best-case. In the worst-case scenario, the occupancy of the robot is set at 50 percent, which will negatively influence the day price of the robot. The cement is still be bought off the robot development company Cybe and efficiency of the employees is rather low since they are not able to combine tasks such as operating the robot and placing the wiring and piping.

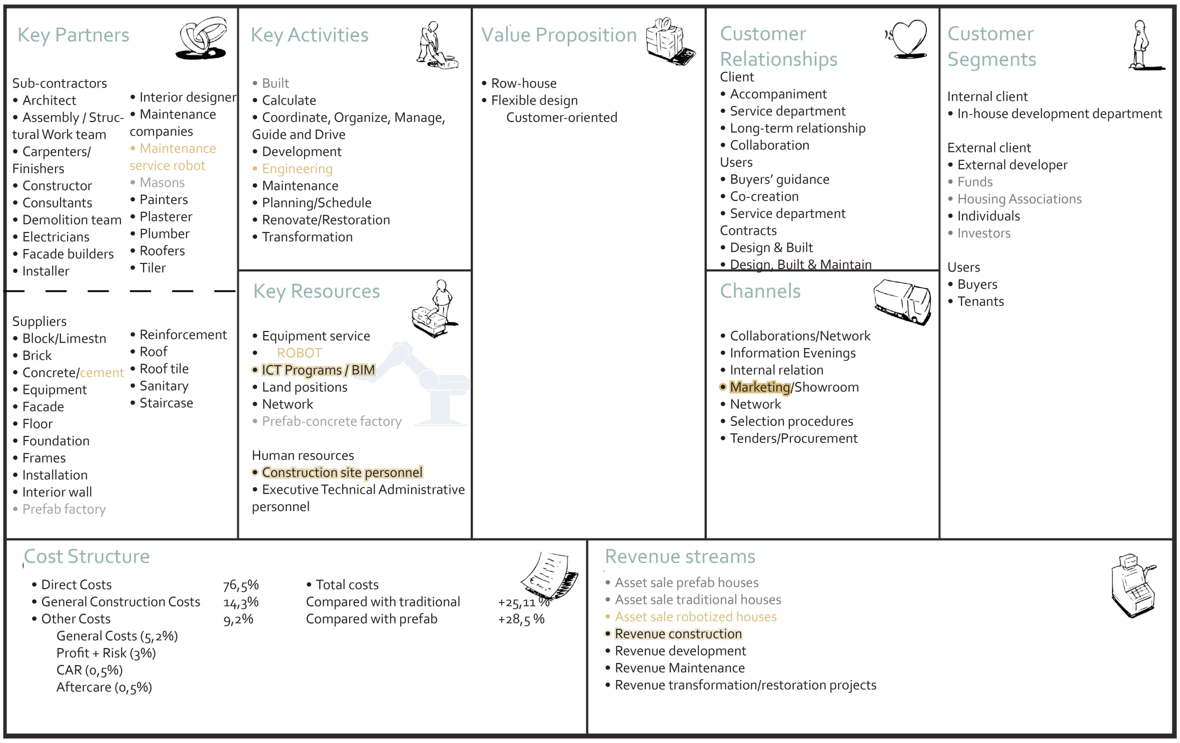


Figure 40 Business model strategy 3, worst-case scenario (own image)

Value proposition

Row-houses are still the main product of construction companies. However, due to the implementation of robots, the design becomes more flexible and will be highly customer oriented. Therefore, robots are not only seen as process but also product innovation. Even just before printing customers can adjust the design because the preparation time is shorter than in a traditional construction process. Less transportation and materials are needed, and therefore the 3D printed house will be more sustainable. Of course, the printer can also be used for 'standard' design. However, it will be most profitable to use it for the customer made, unique designs. Because the robot will be purchased by the construction company itself, a high occupancy rate of the robot is important for the return on investment. Therefore, they will earlier choose to construct with the robot, instead of prefab or traditional.

Customer segment

The customer segment will remain the same. Construction companies for internal development department, the external developer, funds, housing associations, individual and investors. The 3D concrete printing robot will be most valuable for construction projects of owner-occupied houses since the design can be adjusted to the buyers' preferences. This construction method is therefore especially suitable for individual customers and internal developers. Funds, housing associations and investors mainly build rental properties, which should be suitable for different types of residents.

Customer relationship

Small changes can occur in the customer relationship, due to the possibilities with the 3D concrete printing robot. When the robot is used for a customer-oriented design, the co-creation between the clients and construction company will become more intense than in case of the small variations possible with the traditional or prefab construction method. The contract types will remain.

Channels

Construction companies have different ways of approaching customers and acquire jobs. This will not change in general. However, a 3D printed house might be good for the marketing.

Key activities

The key activities changes, since the construction company is purchasing the robot, they have to operate the robots themselves. Therefore, their share in the construction process will increase. In addition, they need to engineer the design and prepare the design for the 3D concrete printing robot.

Key resources

In this strategy, the key resources of construction companies will change. The robot will be purchased by the construction company itself. Therefore, the engineering and operation will be done internally, which requires new ICT programs and personnel should be trained or newly hired to operate the robot. Given the shortage of construction workers, the robotised construction robot will ensure the construction continuity, since there are only two employees needed. However, the construction of the walls is only a small part of the total construction process and will thus minimally influence the human resources. When the construction company owns a prefab factory, the factory might slowly take off in production. However, prefab floors are still needed. In addition, to ensure return on investment, the occupancy of the robot should be as high as expected. Therefore, the construction company will prefer constructing with the 3D concrete printing machine.

Key partners

A new supplier will be added to the key partners, the company of which the robot will be purchased will also be the service and maintenance party and will sell the cement for the robot. In addition, a new supplier for reinforcement has to be found. In addition, a tent should be rented from an external equipment party. Depending on the specific construction company less external assembly workers are needed to construct the shell, because only two (in-house) employees will operate the robot. The need for masons will also decrease, they are only needed for the brick façade. This is beneficial since the scarcity of construction workers will grow the upcoming years. In case of an external prefab factory, the production will slow down; only floors will be purchased.

Cost structure

		Traditional project	Prefab project	Strategy 3 WCS
Total price difference		100 %	97,3%	125,1 %
Direct costs	Labour	8,2%	5,4%	9,4 %
	Material	17,5%	11,6%	12,2 %
	Equipment	0,9%	0,3%	8,3 %
	Sub-contracting	47,5%	61,1%	46,7 %
General construction site costs		16,7%	12,5%	14,3 %
Other costs		9,2 %	9,2 %	9,2 %

Table 16 Relative cost structure strategy 3 WCS (Based on the numbers of Heijmans and own calculations)

The total construction costs will increase by 25,1 percent compared with the traditional construction method and will be 28,5 percent more expensive than prefab. This has to do with the increase in direct costs. The robot will be purchased by the equipment department of the construction company and is internally rented based on day prices. In this scenario, an occupancy of 50 percent is taken. Therefore, the rental price is quite high. Since in this strategy, own employees will operate the robot, labour costs increased. Compared to the traditional construction method, the equipment increases since a construction tent is needed. The general construction site costs have increased in this situation. Since only one printer will be purchased the construction time increased with one week, which has resulted in higher general construction site costs decreases. An important note, the construction of the walls will happen on-site but within a tent. Therefore, this construction method is less independent and thus increasing cost due to weather delay can be prevented. The share of the other costs remains the same for all the strategies. The total cost calculation can be found appendix 14.10.

Revenue streams

The revenue streams slightly increase. The robotised houses will get a share in the asset sale. Since the construction company will have a bigger share in the overall construction activities, the revenue of construction will slightly increase.

9.4.4 Strategy 3: Robotised contractor model, best-case scenario

In the best-case scenario of the third strategy, the robot will be purchased by the equipment department of the construction company itself, and will thus be part of the key resources of the company. In the best case, the occupancy is set at 80 percent, which will positively influence the rental price of the robot. The cement will be developed by the own concrete development department of the construction company which will highly reduce the costs. Last the efficiency of the employees is higher than in the worst case since in this scenario is assumed that the operational team is also able to do the wiring, piping and plastering, which will increase the efficiency and thus reduces the costs.

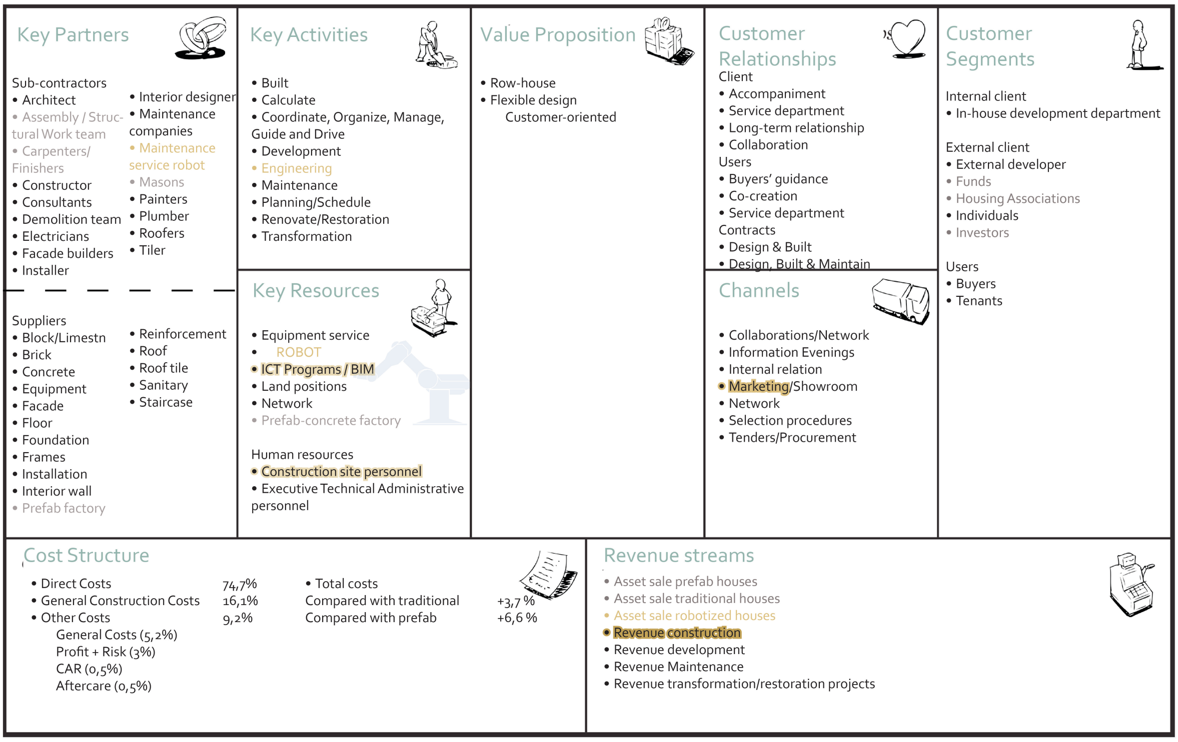


Figure 41 Business model strategy 3, best-case scenario (Own image)

Value proposition

Row-houses are still the main product of construction companies. However, due to the implementation of robots, the design becomes more flexible and will be highly customer oriented. Therefore, robots are not only seen as process but also product innovation. Even just before printing customers can adjust the design because the preparation time is shorter than in a traditional construction process. Less transportation and materials are needed, and therefore the 3D printed house will be more sustainable. Of course, the printer can also be used for 'standard' design. However, it will be most profitable to use it for the customer made, unique designs. Because the robot will be purchased by the construction company itself, a high occupancy rate of the robot is important for the return on investment. Therefore, they will earlier choose to construct with the robot, instead of prefab or traditional.

Customer segment

The customer segment will remain the same. Construction companies for internal development department, the external developer, funds, housing associations, individual and investors. The 3D concrete printing robot will be most valuable for construction projects of owner-occupied houses since the design can be adjusted to the buyers' preferences. This construction method is therefore especially suitable for individual customers and internal developers. Funds, housing associations and investors mainly build rental properties, which should be suitable for different types of residents.

Customer relationship

Small changes can occur in the customer relationship, due to the possibilities with the 3D concrete printing robot. When the robot is used for a customer-oriented design, the co-creation between the clients and construction company will become more intense than in case of the small variations possible with the traditional or prefab construction method. The contract types will remain.

Channels

Construction companies have different ways of approaching customers and acquire jobs. This will not change in general. However, a 3D printed house might be good for the marketing.

Key activities

The key activities changes, since the construction company is purchasing the robot, they have to operate the robots themselves. Therefore, their share in the construction process will increase. In addition, they need to engineer the design and prepare the design for the 3D concrete printing robot. In this scenario, the share in the construction process will even increase more, since the operation team can also do the plastering, wiring and piping task while printing.

Key resources

In this strategy, the key resources of construction companies will change. The robot will be purchased by the construction company itself. Therefore, the engineering and operation will be done internally, which requires new ICT programs and personnel should be trained or newly hired to operate the robot. Given the shortage of construction workers, the robotised construction robot will ensure the construction continuity, since there are only two employees needed. In this scenario, the operation team will operate the robot, and to other carpenter activities, therefore a new team have to be trained. However, the construction of the walls is only a small part of the total construction process and will thus minimally influence the human resources. When the construction company owns a prefab factory, the factory might slowly take off in production. However, prefab floors are still needed. In addition, to ensure return on investment, the occupancy of the robot should be as high as expected. Therefore, the construction company will prefer constructing with the 3D concrete printing machine.

Key partners

A new supplier will be added to the key partners, the company of which the robot will be purchased will also be the service and maintenance party and will sell the cement for the robot. In addition, a new supplier for reinforcement has to be found. In addition, a tent should be rented from an external equipment party. Depending on the specific construction company less external assembly workers are needed to construct the shell, because only two (in-house) employees will operate the robot. The need for masons will also decrease, they are only needed for the brick façade. Also, external partners for the plastering, piping and wiring are no longer needed. This is beneficial since the scarcity of construction workers will grow the upcoming years. In case of an external prefab factory, the production will slow down; only floors will be purchased.

Cost structure

		Traditional project	Prefab project	Strategy 3 BCS
Total price difference		100 %	97,3%	103,7 %
Direct costs	Labour	8,2%	5,4%	11,3 %
	Material	17,5%	11,6%	14,7 %
	Equipment	0,9%	0,3%	6,5 %
	Sub-contracting	47,5%	61,1%	42,2 %
General construction site costs		16,7%	12,5%	16,6 %
Other costs		9,2 %	9,2 %	9,2 %

Table 17 Relative cost structure strategy 3 BCS (Based on the numbers of Heijmans and own calculations)

The total construction costs will slightly increase by 3,7 percent compared with the traditional construction method and will be 6,6 percent more expensive than prefab. This has to do with the increase in direct costs. The robot will be purchased by the equipment department of the construction company and is internally rented based on day prices. In this scenario, an occupancy of 80 percent is taken. Therefore, in this scenario, the equipment costs dropped radically. Also, the cement costs dropped, since the cement is developed in-house. Since in this strategy, own employees will operate the robot, labour costs increased. Compared to the traditional construction method, the equipment increases since a construction tent is needed. The material. The general construction site costs will remain the same. Although the construction time of the walls increased, due to the efficiency of the operation team, which is capable of doing the plastering, piping and wiring tasks, the total construction time remains the same compared to the traditional construction method. An important note, the construction of the walls will happen on-site but within a tent. Therefore, this construction method is less independent and thus increasing cost due to weather delay can be prevented. The share of the other costs remains the same for all the strategies. The total cost calculation can be found appendix 14.10.

Revenue streams

The revenue streams slightly increase. The robotised houses will get a share in the asset sale. Since the construction company will have a bigger share in the overall construction activities, the revenue of construction will slightly increase.

9.5 Conclusion

This chapter provides an answer to the sub-question: 'How will individual aspects of the currently used business model of construction companies change due to the use of robots?'

There are three different strategies in which robots can be implemented. The robot can be introduced by a new sub-contractor who takes over the whole job (strategy 1), the robot can be hired as external equipment service by a supplier (strategy 2), or the robot can be purchased by the internal equipment department of the construction company (strategy 3). Each scenario brings difference changes with it.

Value proposition

In all the three scenarios, row-houses will still be the main product of a construction company. Nevertheless, a shift to a flexible and custom made design will be the result of 3D concrete printing robots. Since they are able to construct complex and unique designs. Even in a late stadium, changes to the design can still be made. Therefore, robots are not only seen as a process but also product innovation.

Customer segment

Since construction companies will still produce row-houses, the clients will not change. However, the flexibility will be more used by initiators who construct owner-occupied houses, since a specific customer made rental property is not in first instance necessary for a housing association or investors. In addition, this eventually can make it harder to find second-generation tenants. Even though this will be highly valuable for the individual customer, but most of the largest companies do not construct individual products.

Customer relationship

The customer relationship does not change that much in each of the scenarios. However, due to the increase of customer made possibilities, a higher customer involvement is required in case of co-creation.

Channels

The channels stayed unchanged in all the scenarios. It is good to mention that 3D printing can have a positive influence on the marketing.

Key Activities

The key activities are changing according to the different strategies. In strategy 1, the robot will be used by sub-contractors, who execute the complete job. Therefore, in this strategy, no change will occur. In strategy 2, where the robot will be hired from an external party, own employees have to operate the machine. Therefore, a bigger share in the construction process will be obtained. Also, knowledge of engineering is required, since this will be an extra activity. This also applies to strategy 3. In addition, in the best-case scenario, the employees who are operating the robot are also able to do the plastering, wiring and piping while printing. Therefore, the share in the construction process will even be larger.

Key Resources

For all the strategies, it is applicable that the production of an own prefab factory will slow down, just floors are still required. Given the shortage of construction workers, the robotised construction robot will ensure the construction continuity, since there are only two employees needed. Strategy 1 will hardly have an impact on the key resources. Only fewer internal carpenters are needed for the construction of walls. However, the construction of the walls is only a small part of the total construction process and will thus minimally influence the human resources. In strategy 2, the own employees have to be trained, or new ones with knowledge of robotics need to be hired. In addition, new software needs to be discovered. In strategy 3, the equipment department is purchasing a robot. Therefore, an equipment department is crucial. In addition, same changes as to strategy 2 apply. However, for the best-case scenario, the operating team needs to be trained not just in operating the robot, but also in the plastering, piping and wiring activities. To calculate the construction, an internal constructor is recommended.

Key Partners

For all the strategies, it is applicable that the production of an external prefab factory will slow down. However, floors are still required. For all the strategies, the key partners will change. In strategy 1, a new sub-contractor will be added, who is executing the wall construction job. In this case, less external assembly workers might be needed. In case of traditional construction, no masons for limestone constructions are needed, neither are suppliers of limestone. In strategy 2, where an external equipment service will be added with a robot, the same changes will happen. In addition, a supplier of reinforcement is needed, an external equipment party for a construction tent is needed, and a supplier of fast-drying cement is needed. In strategy 3, a service supplier of the robot is added for the maintenance of the robot. However due to the increasing share in the construction process and the executing of piping, wiring and plastering fewer sub-contractors are needed.

Cost Structure

	Strategy:	1	2	3 WCS	3 BCS
Total price difference		123,9 %	120,4 %	125,1 %	103,7 %
Direct costs	Labour	6,1%	9,8 %	9,4 %	11,3 %
	Material	12,1%	12,7 %	12,2 %	14,7 %
	Equipment	1,8%	1,9 %	8,3 %	6,5 %
	Sub-contracting	57,2%	52,6 %	46,7 %	42,2 %
General construction site costs		13,5%	13,9%	14,3 %	16,6 %
Other costs		9,2 %	9,2 %	9,2 %	9,2 %

Table 18 Relative cost structure strategy 3 BCS (Based on the numbers of Heijmans and own calculations)

Due to the different changes, the cost structures will also vary. In strategy 1, one expensive sub-contractor is added who is executing all the jobs. Therefore, this scenario turned out to be the most expensive. In strategy 2, the robot will be rented. However, cement, reinforcement etc. need to be purchased. This strategy turned out to be less expensive as strategy 1. Strategy 3 turned out to be the cheapest for the best-case scenario but is still 3 percent more expensive than the traditional construction method. There is a big difference compared to the other two strategies; this is caused by the development of own cement and the increase in productivity due to the increasing share in the construction project. These new strategies compared with the traditional one has mainly shifted cost from the labour costs to the sub-contracting item of direct costs. In general, the construction time remains the same. Therefore, the general construction site costs have not changed in three of the four strategies. Only in the worst-case scenario of strategy 3, the general construction costs slightly increased, due to the longer construction time.

Revenue Streams

The revenue streams are based on the own share in the project. Therefore, strategy 1 has limited influence. In strategy 2, more is executed by the construction company, but the largest influences will be seen in strategy 3 since in this scenario the share of the construction company will be the largest.

F CONCLUSIONS

10 DISCUSION

In this chapter, the findings from literature and practice, as well as the designed strategies for construction companies to implement a robot will be discussed, before the overall conclusion will be given.

10.1 Expectation of literature in practice

For this research, a 3D concrete printing robot has been chosen. Initially, the description of a 3D printer does not immediately meet the requirement of the term robot. Therefore, the definition of a robot a had to change during the graduation. Since literature already spoke about artificial intelligence and a large scale of different automated robots, it was expected that in practice many of these robots would be available for construction. However, this was not the case. Therefore, the definition of a robot had to be adjusted, in response to the in practice available on-site robots. In addition, the 3D concrete printing robot has minimal influence on the business model, compared to an expected available multi-task robot.

Loosen (2002) compared different size construction companies and concluded that, small companies rather focus on the realisation phases and limited outsource activities. While the role of large construction companies shifted towards more a management company. The latter can be confirmed by practice. Although a large share of the construction process is outsourced, they still see 'constructing' as one of their key activities. In this research seven large and one medium company is researched; the difference between the large and medium companies in practice turned out to be minimum. Also, the medium company outsourced an equal share of the construction activities to sub-contractors and had as less construction site personnel as the large companies. However, implementing a robot in a medium size company is difficult, since they have no internal equipment service.

During the research of Pekuri (2015) he concluded that there is limited knowledge of business models in the construction industry and that within a company different definitions are given to a business model. This is completely confirmed during the interviews. It turned out to be the most difficult question. Moreover he stated that the construction companies are an 'anything to anyone' business and although the business models can be used as a filter to select suitable projects, the construction industry realised all the offered projects. However, Dutch construction companies are using their business model as a selection tool. Especially after the recession, since there is enough work, they are rejecting project which does not suit the companies' focus. Last, Pekuri (2015) also investigated that there is no generic business model of construction companies in Scandinavia. Although the elements are all the same, the combinations of elements make the business model of construction companies different.

10.2 Discussion of practice

The choice for this robot was supported by the graduation company. However, interviews with various construction companies showed that the choice of a 3D concrete print robot would not be the first interest of the interviewed construction companies. They would rather invest in research on a masonry robot or a finishing robot, as masonry is scarce and costly, and the finishing phase is the most time-consuming. As a result, the focus group participants also struggle to brainstorm within an existing business model with a 3D print robot. Also, according to practice, the choice of a 3D print robot relates to costumer-made construction, this feature is not optimal used while producing high standardised row-houses. The standardised process of row-houses is currently optimized by prefabricated factories. The added value of 3D concrete print robot is the possibility to construct unique projects with complex design. Therefore, the 3D concrete printing robot would be more valuable for a niche market in villas or other unique projects such as theatres or landmarks. It is important that the robot is a means and not a purpose in itself.

As an inspirational case study the dairy industry has been investigated. This is a completely different industry, but the reason to robotisation is similar. However, wherein the dairy industry robots are used for process innovation, it can be said that robots will bring both, a process and product innovation in the construction industry. Not only the construction process changes, but the product also becomes much more customer-oriented. Therefore, comparison with the dairy industry may not have been the best choice. Nevertheless, no other industry could have served as a better comparison. Although the manufacturing industry is highly standardised, it has no complex supply chain and operates exclusively in conditioned environments, while this research is about mobile robots. A second case study could contribute to a better comparison.

10.3 Discussion of adjusted business models

This research provides three different strategies in which robots are applied in the existing business model of construction companies. The three different scenarios are illustrated according to a business model canvas. Additionally, a business case for a row-housing project is calculated. It is important to remark that a business case does not show the feasibility of a robot in an organisation, but just in a particular project. An overall earnings model could have shown the break-even point of a robot; it could have demonstrated how many projects or houses should be constructed with a 3D printing robot. However, it was impossible to receive all the needed information for such a calculation. Therefore, four business cases have been calculated. However, some costs are not taken into account in these calculations. For example, the need of WIFI, water and electricity are excluded as well as the costs the train or educated a new operation team. In this calculation, it is also expected, that the costs of a constructor are included in the general costs of a construction company. Also, the costs of the own developed cement in the best-case scenario of strategy 3 is an assumption, based on the information of an expert and might thus differ in reality. Last, the 3D concrete printing robot can be used for other construction purposes, this is not taken into account in this research.

An added value, who could not be expressed that well in numbers is the benefit of the increased flexibility of the robotised construction method. First of all, it will ensure that construction companies can continue also constructing when the shortage of construction workers increase since less and another type of employee is needed. Secondly, multiple activities can be done at the same time. Third, adaptation in the design can be made until the moment of construction which increase adjustability of the dwellings for users. Last, this construction method can continue in all-weather circumstances.

Although scientifically three scenarios are possible, practice indicates that an urgency is needed before construction companies actually will apply robots. When the shortage of craftsman increases, the prefabricated factories are run out of capacity, and the speed and cost of a robotised construction process are improved, they give robots a change. However, it must be demonstrated that there is enough continuity of construction projects to make robots feasible. Otherwise, it will not be a viable investment for the internal material service. If the professionals have to choose one of the strategies, the first strategy would be the most realistic. The strategy in which robot is purchased by a sub-contractor seems most likely. However, they decided for this strategy before they had seen the cost calculation, therefore their opinion might be different now, when it is demonstrated that strategy 3 is the financially the most attractive. This will keep the construction company flexible; they can still choose the most appropriate construction method for each project. If the construction company itself buys a robot, it will always happen in a separate entity to minimize risks. However, if you compare this with the dairy farms, which have purchased expensive robots to replace human labour, it is expected that the acquisition of robots for construction companies should be feasible in the future as well when the price of robots drops.

The fact that construction companies once again expect the innovations to be implemented by partners confirm again that the construction industry is conservative. This, however, increases competition for construction companies because there is a chance that innovative (new) sub-contractors can construct themselves without the support of a large construction company. If this is the case and the big construction companies do not innovate, the construction companies will be put offside.

11 CONCLUSION

The objective of this thesis was to investigate the way a business model of a Dutch construction company has to change in order to make on-site robots possible. In order to achieve this objective, several sub questions have been researched and answered in the chapters above. In this chapter, all the sub-conclusions will be brought together in order to answer the main questions: *'How can **Dutch construction companies** adjust their **business model** in order to make **robots** at the **construction site** possible?'*

This research starts with the assumption that a generic business model would be derived from all individual business models of the largest Dutch construction companies. Although there are no unique elements in the business models of the participating companies, when looking to the business models in detail, small variations become visible. As a result, a generic business model cannot be designed to allow robots on the construction site.

By investigating the features of the 3D concrete printing robot, analysing the changing business models in the dairy industry and using input and validation during the focus group, three different models can be created, based on a merged business model. During the focus group, it became clear that the number of internal carpenters, an internal or external prefabricated factory and material service, and having an own internal development department will not affect whether the way of implementing a robot for construction companies. The construction industry is cost-driven, so when a financially profitable construction method can be applied, they will use it. This research has demonstrated the way in which a 3D concrete print robot can be implemented in an existing business model. Finally, there are three different strategies to implement a robot in a construction company that will change the existing business model in a different way. In general, within all the three strategies, the flexibility increases due to the implementation of the robot: the adjustments to the design can even be made just before construction, the construction industry becomes less workforce dependent, which is important due to the increasing scarcity of construction workers and in each weather, circumstance the construction can continue, since the robot can be placed in a construction tent.

In the first strategy, a new key partner will be introduced, who will build the walls on the construction site with a 3D concrete printing robot. This partner will arrange the engineering, the cement, the necessary reinforcement and also bring own workforce to operate the robot. Therefore, the construction company itself does not have to purchase a robot, which ensures flexibility and certainty within the company. For each project, a decision can be made for the best suitable construction method: traditional, prefab or with a robot. This will have an impact on the key business partners of the existing business model. A new partner will be added. In the case of a prefab factory as a supplier, the construction will purchase fewer products. In case there is an internal prefab factory, the productivity will slow down, at least walls will still be produced. Since the new sub-contractor himself brings workforce, this will not directly affect the number of own personnel. This will be comparable to the traditional method; a small proportion being done by own carpenters, but the majority is being outsourced. The construction company remains in this situation as a construction manager and does not increase its share in the construction process. Because it is possible to make changes with a 3D concrete printer and build costumer made homes, it will not only change the process but also the product. A home can even better match the wishes of the customer. In the case of an investor, fund or housing corporation, this will be the initiator. In the case of a developer, the residents will be highly involved in the design. Since the production time of a 3D printer does not appear to be faster than the traditional construction process, he will be busy with two printers for a week; the 3D concrete printer will not be able to set the fastest-built home. As concept-houses are already used as a kind of marketing trick, living in a 3D-printed home will also be a way to market yourself as a construction company. When focusing on the according to the interviewees, most important element of the business model, the financial aspects. Compared with the traditional construction method, the construction with a robot will be 24 percent more expensive and compared with prefab this is even higher, an increase of 27 percent of the cost price is the result. The direct costs rise sharply since the total sub-contracting price is enormous. However, own labour costs and equipment costs decrease, since this is all outsourced. Since the construction time is similar to the traditional construction method, the general construction site costs will remain. The other costs are based on a percentage of the total construction costs and are therefore unchanged. As mason's hourly price will increase sharply in the future, it might reduce construction costs in the future, when masons are becoming scarcer. Additionally, no new revenue streams are created by when the 3D concrete printer is implemented as a sub-contractor. Perhaps, consumers are willing to pay more for such a customer-made house, so maybe the revenue of the properties will increase.

In the second strategy, the 3D concrete print robot remains in the building block of key partners. However, it is now implemented as a supplier. As a result, the robot will be hired as equipment from an external material service. Also, the cement will still have to be taken from the supplier. Compared with the above strategy, this will have more impact on the business model of the construction company. Firstly, employees must be trained or new employees need to be hired to operate the robots and to apply the necessary reinforcement. These are higher educated people, with knowledge of ICT. Also, the builder must use BIM in any case, preferably in the form of Rhino, so that an add-in model can convert the design to a specific file which can be read by the printer. In addition, the engineering responsibility lies with the construction company. Because the construction company will now construct the walls, the construction company will get a bigger share in the construction process. The value proposition, customer segment, customer relationship and channels will not differ from the first described scenario. However, the cost structure and revenue stream will differ. The contractual sum will now be cut into smaller pieces. If the prefab manufacturer is an external partner, it will only have to be paid for the floors, the robot supplier will have to be paid for renting two printers, and reinforcement needs to be paid to the supplier in addition to the traditional cost. In this way, constructing with robots will be 20 percent more expensive than the traditional method and 24 percent more expensive than prefabrication. Different from the first strategy, the own labour costs increase, since own employees will operate the robot, which on its term decrease the sub-contracting costs. The general construction site costs and the percentages of the other costs will be unchanged. As the construction company has a bigger share in the construction process, the turnover of the construction company will also increase. As the robot is still hired externally, this will not affect the construction companies' flexibility; they can still decide to go for traditional, prefab or the 3D concrete print robot.

In the third strategy, the robot will be purchased by the construction company itself. For large construction companies, the equipment service will buy this robot, since they own all the necessary equipment in general. Because a key resource is added to the construction company, this scenario will cause the biggest shift. To start with the key resources, the construction company needs other skilled personnel with knowledge of robots, in order to operate the robot. In addition, increasing knowledge about building and engineering is necessary. The share in the construction activity will increase even more than in the previous strategy. When it is possible to train the robot control team and to teach them how to execute the plastering work, optimal efficiency can be achieved by simultaneously printing and plastering. In addition to the purchase of the robot, new partners will be added. Thus, a service contract with the robot manufacturer will be composed and specific cement and reinforcement from a supplier are needed. For this scenario, the best and worst-case scenarios are calculated. Since the material service will buy the robot with the aid of a mortgage, the day price to rent the robot from the internal equipment service will be dependent on this, as well as the occupancy rate. In order to make a realistic scenario, best and worst case is calculated. In the worst-case scenario in which the robot is still acquired, the occupancy rate will be 50 percent occupancy, for the best-case scenario 80 percent is taken. Also, the efficiency in this last scenario will be higher, since the robot control team will also be able to do other activities such as plastering, wiring and piping. In addition, the construction company will develop fast-drying cement themselves, to reduce costs. While in the worst-case, all these activities have to be executed by different sub-contractors. The final cost for the worst case is 25 percent more expensive than the traditional process and 29 percent more expensive than the prefab process. This has to do with the extremely high costs of the cement and the high rental prices of the robot. Due to the increased share in the construction process, the labour costs increase as well as the equipment costs. In the best case, this is much lower. Based upon the traditional method this will be 4 percent more expensive, for prefab, this is calculated 7 percent. As the construction company itself construct, the share of revenue will also be greater. In this situation, construction companies will be less flexible to choose the best suitable construction method, since they need to achieve the occupancy rate of the robot.

To summarize, there are thus three different scenarios in which a robot can be applied to the building site. Depending on the scenario, the construction companies' share increases in the construction process. By shifting activities, in all three scenarios, other changes will take place in the business model; the change per scenario will primarily take place in the activities, resources, partners, costs and the revenue building blocks. However, in all three scenarios, the cost of the construction process will be higher, so that currently the 3D concrete printing robot will not compete with the traditional or prefabricated construction method. Therefore, a great urgency is needed. Based on the different business models, the last strategy in which a robot will be purchased is financial most beneficial and efficient and will increase the flexibility regarding planning, when the scarcity of workforce increase.

12 REFLECTION AND RECOMMENDATIONS

This chapter looks back on the entire graduation process, the methods used, but also summarizes the lessons learned for practice and recommendations for further research.

12.1 Research process

More than one year ago, I had to choose between two research topics of two different graduation labs. With the first subject, I was quite familiar, and this topic had drawn my attention for quite a long period. The second subject seemed to be far out of my comfort zone and was completely new to me. However, I decided to extend my knowledge and chose to challenge myself with an extremely trendy subject: Robotics. Although I was unfamiliar with robots, during the entrepreneurship annotation which I followed in addition to my master, I found out that business models and innovation were in my interest. I saw this as an opportunity and combined my knowledge of design and construction management and entrepreneurship in this thesis. Also, I extended my knowledge about robotics. Looking back on last year, the conversations and meetings I had with innovation managers, entrepreneurs, trend watchers, directors of large construction companies, and also with farmers, I think that there was not a more suitable research for me than this one. I truly enjoyed the whole process, but of course, there were also tough moments.

The graduation year started already chaotic. In the first semester, I set big goals for myself. With additional entrepreneurship goals, extra electives, research courses and this thesis, my agenda was filled with more than 20 ECTs in one-quarter. If that was not enough, I became part of the BOSS-board, the practice association of the master, for which I had to organise a study trip in the summer of 2017, and I had a part-time job of 12 hours a week. It was no surprise that the proposal phase of the research slowly progressed and a lot of stress was accompanied by submitting my research proposal.

With this unfortunate start, also the literature study became a struggle. By achieving the P2 in February, I could start looking for a graduation company. Heijmans and especially Jurre van der Ven, innovation manager, helped me defining the demarcation of my research. Due to the literature research, I expected that several kinds of robots for construction would be on the market. However, this was not the case. On the advice of the company supervisor, I, therefore, started to look for a case study, in the hope of easily identifying the choice of a specific robot. Although this did not help me finding a suitable robot, it helped me in a way that the change in another industry inspired me somehow. Since the available and 'proven' robots on the market, were not suitable for my research question, which emphasises on-site robots, a solution was found in the 3D concrete industry, in which Jurre was involved a while ago. Therefore, I got in contact with Cybe.

Meanwhile, I was in contact with a lot of (highly interested) construction companies who all like to participate in my research. During a little more than two months, eight companies were interviewed in order to understand the current business model. Although conducting interviews is something I enjoyed, transcribing almost 300 pages was terrifying. Meanwhile, the time flew by, and it was hard staying focused with my graduation thesis since I was responsible for the study trip.

With the gathered information about the current business model of construction companies. I found out there was not something such as archetypes of generic business model possible for construction companies. Therefore, it became hard to make the first draft of an adjusted business model. The first draft was validated by a focus group of experts. This was mainly one of the hardest tasks, to get all the experts together. After two failed attempts at the end of May, it finally took place. I was not satisfied with the result of the focus group, the participants employed different functions, and some did not feel comfortable with themselves. Therefore, the output of this focus group was a little disappointing. With the main result, those calculations are required in order to convince construction companies.

However, conducting financial information, even at the graduation company self-was hard. After several miscommunications and a very busy calculation expert, my supervisor helped me find another expert. Making an appointment with him, was quite challenging and after the summer I finally managed to make calculations. Unfortunately, due to the limited time, it was not possible anymore to validate these findings with experts.

In the end, I look back at a rather successful process. I just know increased my knowledge about robots, business models and construction companies. But also, learned a lot about doing scientific research, about organising focus groups and about planning. Due to the busy schedule, last year it took me three months longer to graduate. In the first instance, while starting, I planned to graduate before summer. Due to my busy schedule and full agenda, I did not accomplish this goal. During last year, I found it quite difficult to combine the board, graduation, my job in the hotel and the internship. However, as Hans Wamelink suggested multiple times during our meetings is that I just had to manage my committee, I had to delegate tasks. All the time, I found it hard to spend jobs. Therefore, I had limited time presented at the graduation company which is regrettable since this was the opportunity to get to know this company. However, after the study trip, with increased pressure with the graduation deadline nearing, I finally used my position in the committee to outsource tasks, just like construction companies.

To conclude this: each start is difficult, and without planning skills, the ends are difficult too. The last few weeks have been a battle against time. Hopefully, it turned out to be successful.

12.2 Validity and reliability

In the preparation of the research, validity and reliability were taken into account. However, when looking back on the process, the following remarks can be made on the chosen research method.

First of all, the explorative interview with the business developer of the 3D-concrete print manufacture might be biased. This company has a monopoly function in the Netherlands. Therefore, other 3D-concrete-print manufacturers outside Europe should be interviewed as well to validate the given features. Or institutes such as the University of Eindhoven could have been interviewed; they are also working on 3D concrete printing. However, to increase the validity and the current state of the art the features, multiple interviews are conducted during the research, with different interviewees. Also, a case study has been made (by the company itself) to show the influences on the construction process. The prices asked, are compared with another 3D printing company. The Dutch company turned out to ask much higher prices. In order

The interviews with construction companies are held with only one person per organisation. In order to increase the reliability, interviews could have been held with different persons in the organisation. Although semi-structured interviews were being prepared, the information per interview differs. To complement the information and to check the designed business model, construction companies were asked to review the findings. However, only four companies completely reviewed the requested documents, two did not apply at all. Therefore, there is a difference in the reliability of current business models. In addition, it was difficult for the interviewee to not steer the answers, by means of additional questions, the interviewee is actually per accidentally sent in a specific direction. Also, some questions were not objective, such as 'It the business model used for the selection of projects?' This already implies that somewhere it is stated that this can be a function of the business model. The question, in this case, could have been: What is the purpose of a business model?

Case studies are just conducted in one other industry, the dairy farms. The findings of this case study are used to redesign the business model of construction companies. The external validity has not been checked. This could have been done by means of a case study in another sector. Therefore, the external validity of the dairy farms is not proved.

The first draft is based on the inspiration gained from the case study, the current business models and impacts which the robot will have, according to the developer of the robot. As a result, the first design is very optimistic. Information such as cheaper, more sustainable, and faster, is assumed as truth, while during a project comparison, it appears that both the speed and cost of the project will not be improved. As this comparison took place, after the focus group, the information and validation during the focus group were too early in the process. Here, much more could have been learned, if a comparison with the traditional and prefab construction methods had already been conducted.

The focus group turned out, not to be the best research method to check the design of a new adjusted business model. Since construction industry is a competitive industry, construction companies are not free to speak. Also, the difference in age and function and the personality of the participants have influenced the outcome. One participant is working for a company which is highly involved in 3D printing. However, he did not admit this during the focus group. One participant took the lead in the discussions; his opinion was adopted by all the other participants. Therefore, the focus group was steered into one direction. This has led to limited discussions. Hence, the observer and the conversation leader had to steer the conversation with statements and questions. Both observer and conversation leader, therefore, influenced the focus group. This should not be the case, in terms of a focus group. Private interviews would have been more valuable for this research.

In general, the data of this research has been collected in Dutch. Therefore, all the information had to be translated into English. This can cause translation errors.

12.3 Limitations of the research

This research has been done to the residential department of Dutch construction companies and is only focused on row-houses. Therefore, not all the benefits and added value of the 3D concrete printing robot is research. Besides, this research has only focused on the large size construction companies. Since the small size construction companies, in general also have individual customers, the robot might have an added value for these companies.

Furthermore, this research should have shown the earnings model of robots in a construction company, but the financial image is just based on business cases and not on the whole organisation. Therefore, the break-even point has not been demonstrated. According to Cybe, 3D concrete printing only interesting and feasible for large size construction projects, due to the prior calculations. However, in this research, it is assumed that costs such as for the contractor are already included in the general costs, and are there left out of the scope. Also, the costs for WIFI, water, electricity and education and retraining of the operational team for the robot are excluded.

This research primarily focused on the current developed robots and features. In the near future, the price of robots will drastically decrease, and it is also expected that the robots will become faster. However, since these are all assumptions this is not included in this research.

12.4 Recommendations for practice

The recommendation for practice is related to the robot manufacturing company as well as to the construction companies. Starting with the construction companies, it is suggested that within the companies more attention should be given to the business model. In the most companies, it is not clear what a business model is, neither to the employees the own business model of the construction works. If even the directors of companies are struggling with their explanation of the business model, this cannot be communicated clearly to the employees. However, with the bright construction future for construction companies, and a lack of craftsmen, innovation of the process or product will be the only solution. According to Pekuri (2015), this will only be possible by the understanding of the current business model, the content and potential, provides a starting point for managers in the construction industry to exploit the possibilities of innovations.

Also, if the only innovation happening in the construction industry is introduced by sub-contractors, this will increase the competitive market. Start-ups, but also companies such as IKEA will take over the construction market, with their new ways of construction. Darwin's quote also counts for construction companies:

'It is not the strongest of the species that survives nor the most intelligent, but the one most responsive to change' - Charles Darwin (1809)

In addition, I agree with all the comments received on the chosen robot. I, indeed think that the 3D concrete printing robot is not satisfying enough to be implemented yet. The price is too high, and the features and thus the influence on the construction process is minimal. At this moment prefab is still, faster and cheaper. However, there are 3D concrete robots which can already print floors. In the case of a total Casco, the efficiency of 3D printers and the influence and benefits on the construction process might be bigger.

As a recommendation for the 3D concrete printing factory, I would suggest rethinking the business strategy. Currently, 3D concrete print manufacturers outside Europa have proven that the cost price of 3D printing can be much lower. For now, the printer might be used for unique projects, but the scope can enlarge when the price decreases. Especially the cement price is way too high. Inventing cheap fast-drying cement is not that difficult for in-house concrete experts of construction companies. When selling the robot to construction companies, with the idea of a razor and blades business model strategy, this company will not survive. When the expensive blades (the cement) can be changed for own developed concrete, the business has to be reconsidered. Also, the service costs compared with the dairy farms, are extremely high. In addition, although they want to sell the robots, the market has proven that they prefer this company as a sub-contractor.

12.5 Recommendations for further research

This research is an explorative research. A first research to the innovation of robot in the construction industry. This research is limited to on-site construction since the prefab factories are already using robots in conditioned environments. However, there is not yet a research published on the available offsite robots.

As a recommendation of the practice, the masonry robot and finishing robot are in the interest of the construction companies, therefore a next research can focus on these robots, which will probably have other impacts on the business models.

To validate this research, more case studies can be done in other industries. And another 3D printing company can be approached in order to recalculate, the case project. I suspect that for example, the Chinese Winsun will be much more affordable and therefore more interesting for construction companies.

Due to the limited time, the legislation in general of robotics in construction is not researched. Before construction companies apply robots, an investigation has to be made, what the specific legislation is, and how they can be met.

Also, the construction companies indicated that robots would just be used when they are faster than the currently used construction methods. However, research can be done to the optimal construction time, since I expect that an increase of construction time will not increase the total project time, due to the long permits application time etc. In addition, initiators also need some time to find possible end-users.

Furthermore, as research has stated that the size of the construction influences the business model and strategy of a company. Research can be done to the different business models of large and small size companies. Perhaps the business model of small size construction companies is more suitable for the implementation of robots.

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14 APPENDICES

The full version of this appendix contains confidential information. The confidential version of this study can be requested by contacting one of the below mentors of the Delft University of Technology.

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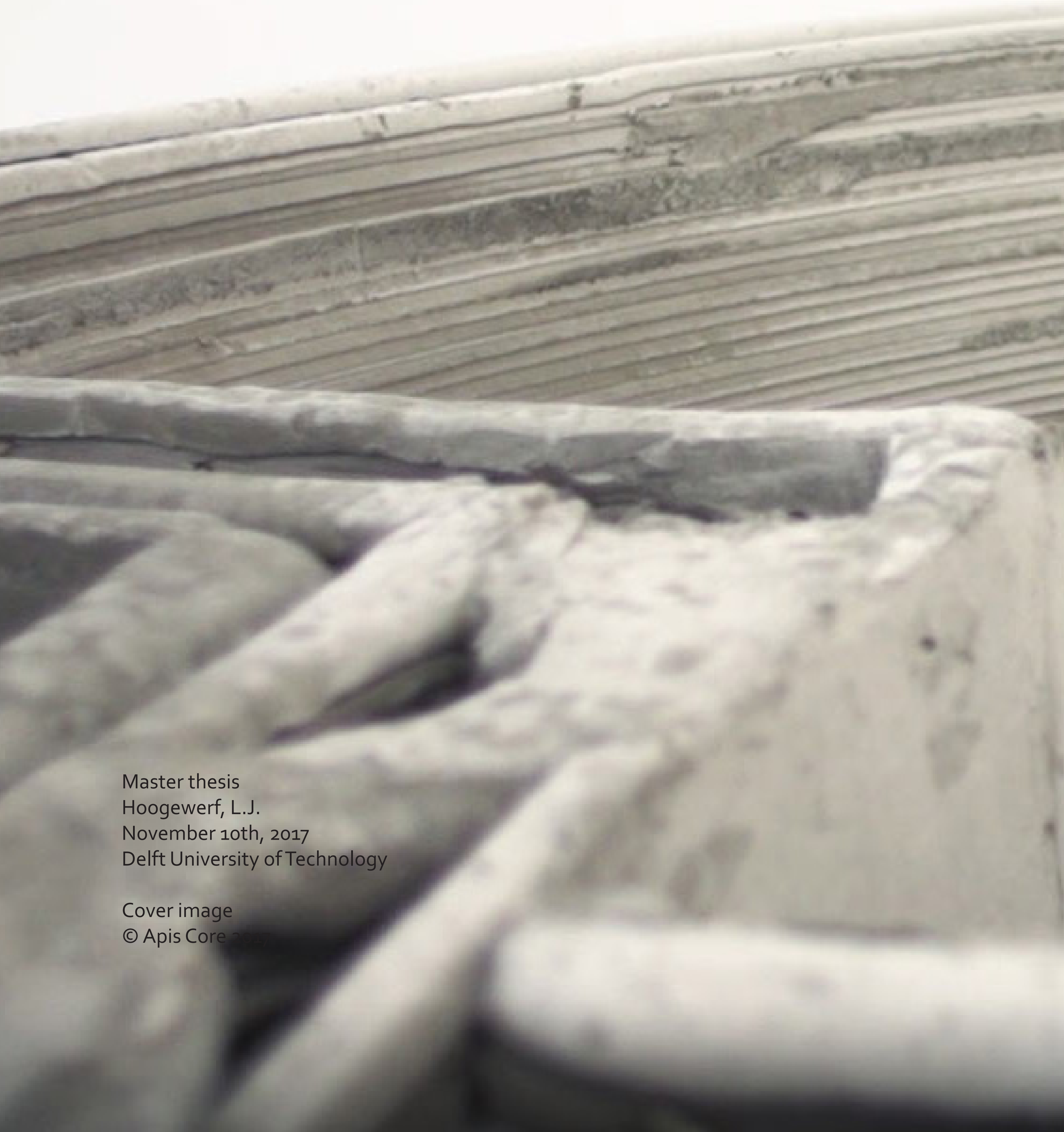

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