Future-Proof Construction Projects in the FMCG Manufacturing Industry within the Context of Industry 4.0

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Master of Science Thesis

Future-Proof Construction Projects in the FMCG Manufacturing Industry within the Context of Industry 4.0

by

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(Front page: picture RoyalHaskoningDHV, case study project 3 in Nigeria)

Preface

This graduation thesis is the final deliverable of my graduation research for the Master of Science Construction Management & Engineering at Delft University of Technology. I conducted my graduation research the past months in collaboration with Royal HaskoningDHV. The process of conducting the research and writing this thesis have resulted into a transition roadmap, which will be elaborately explained later in this thesis and moreover, many personal learnings and developments.

I had the opportunity to learn a lot about the continuously developing subject of my graduation research, from which parts were totally new for me. I conducted the research and wrote the thesis with great pleasure, due to the interesting subject and the great help from many people. I would like to thank everyone who contributed to the content of this research.

Firstly, I had the opportunity to interview more than 20 people from all over the world. From whom I have all learned a lot during the interesting and fun conversations we had. Furthermore, I am very grateful to Royal HaskoningDHV for the warm welcome and the excellent support I received throughout my research. All the colleagues I met at Royal HaskoningDHV were always very helpful and interested in my research.

Secondly, I would like to thank my graduation committee members from Delft University of Technology. The chair of my graduation committee, Hans Wamelink, was the first one committed to my graduation research and helped me throughout the process by always asking the right questions on a high level of abstraction to make sure I would not get lost into detail. Alexander Koutamanis, my first supervisor from the Faculty of Architecture and Built Environment, helped me a lot during our constructive brainstorm sessions, in which he always pushed me to take one step extra and think one step further. Mark de Bruijne, my second supervisor from the Faculty of Technology, Policy and Management, continuously made sure my work was scientifically relevant and valid, by reading all my work carefully and commenting on it on a very detailed level.

Finally, I want to thank my two supervisors from Royal HaskoningDHV, who also took part in my graduation committee. René Dahmen made sure my graduation research could take place at Royal HaskoningDHV and arranged my daily supervisor as support. Moreover, during the meetings we had, he always challenged me to look from an overarching view to my research and visualise my storyline. Last, but certainly not least, Louise Levenbach, my daily supervisor, with whom I spent a lot of time the past months. She always helped me forward with her constructive questions as a member of my graduation. Moreover, she helped me a lot in my role as researcher by helping me to analyse the big amount of visions and information I came across during my research.

As a reader of this thesis, I hope you enjoy reading it as much as I enjoyed writing it.

Jet Merkx
October 2018

Executive Summary

Industry 4.0, the so-called fourth industrial revolution, is a future-oriented strategy to prepare industry for future production (Davies & Sendler, 2018a). The opportunities of the applications and technologies of Industry 4.0 have been researched (Hermann, Pentek, & Otto, 2016; Zhou & Liu, 2016). However, in practice, different industrial sectors, e.g. the fast moving consumer goods manufacturing industry, still lag behind on the possible application and implementation of the possibilities of Industry 4.0 (Fry, Mortlock, Firsova, & Moore, 2017).

The fast moving consumer goods (FMCG) manufacturing industry is one of the largest industries globally (Celen, Erdogan, & Taymaz, 2005). The FMCG manufacturing industry is influenced by trends, such as individualisation of consumer demand, digitisation of operations, etc., throughout its whole value chain from the FMCG manufacturer to the consumer. The construction projects of FMCG factories are also assumed to be influenced by these trends, but are not able to respond to them (Küper, Kuhlmann, Köcher, Dauner, & Burggräf, 2013). Therefore, this research tries to answer the following research question:

What can be done to future-proof the output and process of construction projects in the FMCG manufacturing industry within the context of Industry 4.0?

By means of an explorative research methodology, firstly, data is collected through exploratory interviews and a multiple-case study. Combined with data from a literature review, the current situation of the output (i.e. the FMCG factory) and process of construction projects in the FMCG manufacturing is researched. Furthermore, the trends, challenges and opportunities of Industry 4.0 defining the transition from the current to the future situation, are researched by conducting a literature review. And finally, with all data collected, a design for the future situation and a design for a transition roadmap to the future situation, are made.

The overarching problem of the current output of construction projects in the FMCG manufacturing industry is not being able to manufacturer the specification, volume, moment and location of the demand of the FMCG value chain. The overarching problem of the current process of construction projects in the FMCG manufacturing industry is defined as a poor project process in the perspective of one or more actors in the project organisation. Main actors in the project organisation of construction projects in the FMCG manufacturing industry are FMCG manufacturers, service suppliers (e.g. engineering, design etc.) and process product suppliers process (e.g. original equipment manufacturers).

A PESTE (i.e. political, economic, social, technological and environmental) analysis is used to identify the trends affecting consumer demands, leading to manufacturing challenges in the FMCG manufacturing industry (The World Bank, 2017; United Nations, 2017). Fierce global competitiveness, a big pressure on time, cost and quality, an increasing demand for changeability and integration, are found to be the manufacturing challenges for the FMCG manufacturing industry (Brettel, Klein, & Friederichsen, 2016; Hermann et al., 2016; Kasriel-Alexander, 2012; Zhong, Xu, Klotz, & Newman, 2017). These manufacturing challenges also result into challenges for the construction projects of these factories (Oesterreich & Teuteberg, 2016).

The Industry 4.0 trends defined as opportunities related, to the challenges are: increasing data acquisition, computational power and connectivity, increasing data analytics and intelligence, increasing advanced conversion to the physical world and increasing advanced human-machine interactions. These four trends are linked to specific Industry 4.0 technologies (Küper et al., 2013; Scalabre, 2018).

For the future situation, changeability and integration are introduced as additional project drivers for construction projects in the FMCG manufacturing industry (Davies & Sendler, 2018b; Wang, Wan, Li, & Zhang, 2016; Zhou & Liu, 2016).

For the future output of the specific construction projects, four design concepts are defined: cyber-physical manufacturing, smart manufacturing and modular manufacturing (Hermann et al., 2016; Li et al., 2018; Thramboulidis, 2015). For the future process of the specific construction projects, the Industry 4.0 technologies are mapped out on the different project phases, leading to different durations, a different project organisation and different information management methods (Oesterreich & Teuteberg, 2016).

A transition roadmap is designed for the transition from the current to the future situation of construction projects in the FMCG manufacturing industry, by enhancing the opportunities of Industry 4.0. Different transition steps for the FMCG manufacturer, service supplier and process product supplier eventually lead to the final step of the transition roadmap: co-create a coherent Industry 4.0 strategy, based on the learnings from the previous steps of each actor.

To answer the research question, the generic components of the previous steps of all actors are considered. All actors are recommended to focus on specific Industry 4.0 trend. Moreover, the specific Industry 4.0 strategy, linked to the specific capabilities needed for this strategy, could lead to further exploration and implementation of specific Industry 4.0 technologies. By implementing changeability and integration as additional project drivers, all actors can start developing changeable and integrated parts of their services and products. The realisation of an eco-system of service suppliers and process product suppliers around the construction project of a FMCG manufacturer, in combination with standardised cloud-based documentation and standardised communication strategies, could then be the next step towards future-proof construction projects in the FMCG manufacturing industry.

Limitations of the research context, research design, data analysis and data collection are discussed. The limitations are mostly caused by the combined knowledge fields of the FMCG manufacturing industry, construction projects and Industry 4.0, since not many literature nor theory exists on these combined knowledge fields. Therefore, several recommendations for future research are made, focusing on a more specific part of the combined knowledge field.

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Lists of Abbreviations and Definitions

Abbreviations

Abbreviations			
General		Case study documentation - Output	
CPG	Consumer Packaged Goods	FTS	Fermentation temperature system
FMCG	Fast Moving Consumer Goods	FPS	Full product store
SMCG	Slow Moving Consumer Goods	HVAC	Heating, ventilation and air-conditioning
Organisations		M&E	Manufacturing and engineering
RHDHV	Royal HaskoningDHV	MEP	Mechanical, electrical, plumbing
TUD	Delft University of Technology	PEB	Pre-engineered building
UN	United Nations	PEMB	Pre-engineered metal building
Construction projects in the FMCG manufacturing industry		Pre-fab	Pre-fabricated
		SDC	Standard distribution centre
Capex	Capital expenditures	WWTP	Waste water treatment plant
Opex	Operational expenditures	WTP	Water treatment plant
EPCm	Engineering, procurement, construction management	Case study documentation - Process	
		AB	As built
OpCo	Operational company	BD	Basic design
Manufacturing steering systems		CD	Concept design
ERP	Enterprise resource planning	CM	Construction management
MES	Manufacturing execution systems	DD	Detailed design
PLM	Product lifecycle management	FC	For construction
CRM	Customer relationship management	MP	Masterplan
Industry 4.0 technologies		PA	Permit application
AR	Augmented reality	PD	Preliminary design
VR	Virtual reality	PO	Production order
BIM	Building information modelling	PDB	Project data book
CAD	Computer aided design	RfP	Request for price
GUI	Graphical user interface	SOP	Standard operating procedure
IoT	Internet of things	SD	Structural design
RFID	Radio frequency identification	TD	Tender design
		TP	Tender package

Table A - Abbreviations

Definitions

In the context of this research: process and output of construction projects	
Construction project	Project with a process from initiation to exploitation and an output of a built object.
Process of construction project in the FMCG manufacturing industry	Process from initiation to exploitation phase of construction project in the FMCG manufacturing industry.
Output of construction project in the FMCG manufacturing industry	FMCG plant with FMCG factory.

In the context of this research: manufacturing environment, manufacturing facility and manufacturing system	
Manufacturing environment	Plant with factory.
Manufacturing facility	Civil part of plant with factory: plant logistics, building, utilities, etc.
Manufacturing system	Process part of factory: manufacturing machinery and equipment.

Plant and factory (American Industrial Works, 2018)	
Plant	Collection of industry related buildings: factories, distribution centres, warehousing, etc.
Factory	Building in which products and/or are manufactured. A facility which mass-produces one type or multiple types of products and/or goods.

Production, manufacturing, FMCG manufacturing, product and good (Kulp, Lee, & Ofek, 2004)		
Production	Process of converting inputs in to outputs (broader term, every type of manufacturing can be production, but every production is not manufacturing).	
Manufacturing	Process of converting raw material into finished products by using various processes, machines and energy (narrow term).	
	Product	In the context of this research: Output of general manufacturing process.
FMCG manufacturing	Process of converting raw material into consumer packaged goods (CPG), by using various, processes, machines and energy.	
	Good	In the context of this research: Output of FMCG manufacturing process.

Machine, machinery and equipment (Processing & Packaging Machinery Association, 2016)	
Machine	Object made up of a number of parts designed to perform a task. It has an input, normally power of some description, and generates an output such as a product or a movement.
Machinery	Collection of machines that operate together to perform a task.
Equipment	Necessary items for the purpose of the factory and its machinery. Equipment does not convert anything into anything else but supports the factory and its machinery.

Party, actor, stakeholder (Leijten, 2016)		
Party	Party with specific authorities but not necessarily connected to the project. Party can be unconnected to the project, can be an actor, can be a stakeholder or can be both an actor and a stakeholder.	
Actor	Party that influences the project and has an interest in the process and/or output of the project.	
	Internal actor	Actor part of the project organisation.
	External actor	Actor not part the project organisation.
Stakeholder	Party that does not directly influence the project but does have an interest in the process and/or output of the project.	

Table B - Definitions

Research Context

(Picture Royal HaskoningDHV, case study project 1A in Ethiopia)

Research Context

The first part of this thesis, the research context presents relevant background information for the rest of this thesis, in two chapters. The first chapter introduces the research (Chapter 1). In the second chapter the research methodology is presented (Chapter 2).

1
Introduction

This chapter introduces the research in three paragraphs. The first paragraph introduces the research context (Paragraph 1.1). The second paragraph introduces the research gap (Paragraph 1.2) and in the third paragraph the thesis structure is presented (Paragraph 1.3).

1.1 Research Context

This paragraph introduces the research context. The paragraph is divided into three sub paragraphs. The first paragraph introduces the concept of Industry 4.0 (Paragraph 1.1.1). The second paragraph introduces fast moving consumer goods (Paragraph 1.1.2) and in the third paragraph construction projects are introduced (Paragraph 1.1.3).

1.1.1 Industry 4.0

Since the first industrial revolution at the end of the 18th century, the term industry has been used to describe all economic activity concerned with the processing of raw materials and manufacturing of goods in factories (Preuveneers & Ilie-Zudor, 2017). After the second and the third industrial revolution, the term Industry 4.0 was first introduced by the German government in 2013, describing the fourth industrial revolution (Figure 1-1). Industry 4.0 is a future-oriented strategy to prepare industry for future production (Davies & Sendler, 2018a). As defined by Smethurst et al. (2016, p. 5): *"the fourth industrial revolution, ... is used to describe the increasing digital connectivity of consumer, product, process and factory through the use of emerging and disruptive technologies"*.

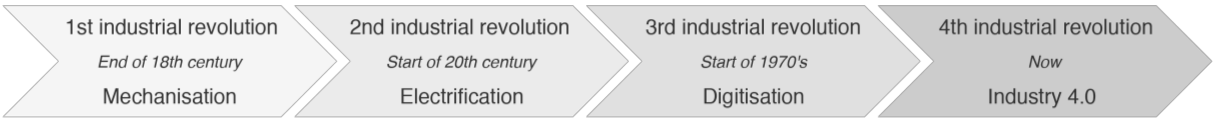


Figure 1-1 - Industry 4.0 - Industrial revolutions (Own figure, based on Preuveneers & Ilie-Zudor, 2017)

Now, more than five years after Industry 4.0 was first introduced, scientific research has been done on the different aspects of Industry 4.0. The origin and the definition (Zezulka, Marcon, Vesely, & Sajdl, 2016), its applications and technologies (Davies & Sendler, 2018a) and implementation strategies (Hermann et al., 2016; Zhou & Liu, 2016) have been researched. However, in practice, different industrial sectors, e.g. the fast moving consumer goods manufacturing industry, still lag behind on the possible application and implementation of the possibilities of Industry 4.0 (Fry et al., 2017).

1.1.2 Fast Moving Consumer Goods (FMCG)

As part of the consumer goods market and the consumer goods manufacturing industry (Figure 1-2), the fast moving consumer goods (FMCG) market and the FMCG manufacturing industry account for more than half of all global consumer spending. Therefore, it is one of the largest industries globally (Celen et al., 2005).

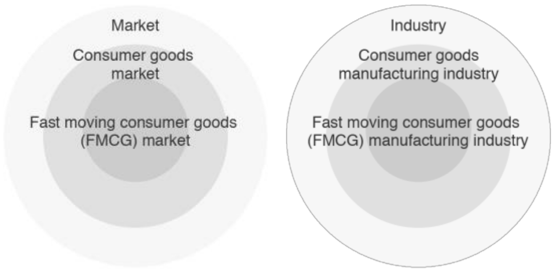


Figure 1-2 - FMCG - Markets and industries (Own figure, based on Celen, Erdogan, & Taymaz, 2005)

Consumer goods are end-products purchased for consumption by consumers (Bucklin, 1963, p. 50). Three main types can be distinguished: slow moving consumer goods, fast moving consumer goods and services (Bucklin, 1963, p. 50). FMCG can be divided in four main categories: household care, personal care, health care and food and beverages (Steenkamp & Geyskens, 2014).

In the value chain of FMCG, raw materials go from supplier to the FMCG manufacturer. Consumer packaged goods (CPG) go from the FMCG manufacturer, through the FMCG retailer (e.g. supermarket), to the consumer (Figure 1-3). Before the fourth industrial revolution, the value chain only had a purely logistic function, but nowadays this function has shifted to the integration of advanced planning processes and operations between all actors involved. For example, the automatic control of supply and demand throughout the whole value chain (Alicke, Rexhausen, & Seyfert, 2017).

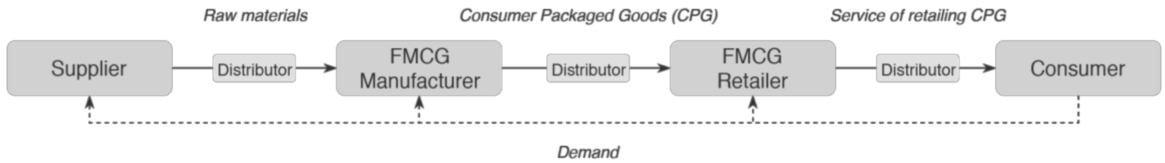


Figure 1-3 - FMCG - Simplified value chain of FMCG
(Own figure, based on Battezzati & Magnani, 2000)

FMCG differ in specific characteristics for the various actors in the value chain of FMCG (Table 1-1). For example, the little time on purchase decisions from the consumer perspective (Nijssen, 1999) and the high and increasing competition within the FMCG market from the FMCG manufacturer and FMCG retailer perspective (Bascle et al., 2012). These different perspectives show the pressure on the FMCG manufacturer and FMCG retailer caused by the consumer demands and the need for effective control of supply and demand throughout the value chain.

FMCG manufacturer perspective	FMCG retailer perspective	Consumer perspective *
Low profit margins on individual FMCG, but high volumes of manufacturing and sales (Fry et al., 2017)		Individual goods are cheap, but all FMCG together form significant part of budget (Fry et al., 2017)
Focus on time-to-market when turning raw materials into consumer packaged goods (CPG) (Van Wezel, Van Donk, & Gaalman, 2006)	Shelf life (time that goods can be stored without becoming unfit for use) of FMCG shorter than one year (Taoukis & Giannakourou, 2004, p. 52)	Frequently purchase of FMCG and limited inventory of FMCG, since goods are perishable (Constantinides, 2004)
Competition is high and increasing within the FMCG market and creates greater demand on supplying actors with respect to time, cost and quality (Bascle et al., 2012)		Little time on purchase decision and low consumer involvement (Nijssen, 1999)
The range of goods is extensive and with a continuous demand to improve and optimize the goods to the developments in the consumer market (Duivenvoorden, 2017)		Goods include necessities, comforts and luxuries (Steenkamp & Geyskens, 2014)

** In the simplified value chain, no division is made between consumer and customer, so in this table the consumer perspective also covers the customers perspective. The customer buys the good and the consumer uses the good (Battezzati & Magnani, 2000).*

Table 1-1 - FMCG - Characteristics FMCG from different perspectives
(Bascle et al., 2012; Battezzati & Magnani, 2000; Constantinides, 2004; Duivenvoorden, 2017; Fry et al., 2017; Nijssen, 1999; Steenkamp & Geyskens, 2014; Taoukis & Giannakourou, 2004; Van Wezel et al., 2006)

Manufacturing can be defined as the process of converting raw materials into finished products. FMCG manufacturing specifically, as part of the FMCG value chain (Figure 1-3), can be defined as the process of converting raw materials into consumer packaged goods (CPG) (Table 1-2) (Kulp et al., 2004).

<table>
<tr><th colspan="3">Definitions of production, manufacturing, FMCG manufacturing, product and good</th></tr>
<tr><td>Production</td><td colspan="2">Process of converting inputs in to outputs (broader term, every type of manufacturing can be production, but every production is not manufacturing).</td></tr>
<tr><td rowspan="2">Manufacturing</td><td colspan="2">Process of converting raw material into finished products by using various processes, machines and energy (narrow term).</td></tr>
<tr><td>Product</td><td>In the context of this research: Output of general manufacturing process.</td></tr>
<tr><td rowspan="2">FMCG manufacturing</td><td colspan="2">Process of converting raw material into consumer packaged goods (CPG), by using various, processes, machines and energy.</td></tr>
<tr><td>Good</td><td>In the context of this research: Output of FMCG manufacturing process.</td></tr>
</table>

Table 1-2 - FMCG - Definitions of production, manufacturing, FMCG manufacturing, product and good (Kulp et al., 2004)

FMCG manufacturing environments have different characteristics than general manufacturing environments (Table 1-3). For example, the machinery and equipment are specialised for the FMCG manufacturing industry and are suitable for bulk manufacturing (Rhodes, 2014). These differences show the distinctive character of FMCG manufacturing environments compared to general manufacturing environments and the need for a specific approach for the design and construction of these environments.

Characteristics general manufacturing environments	Characteristics FMCG manufacturing environments
Converting raw materials into finished goods	Converting raw materials into consumer packaged goods (CPG)
Complex machinery and equipment	Specialised process machinery and equipment for FMCG manufacturing industry *
Large scale manufacturing	Bulk manufacturing
Labour intensity depends on sub-sector	More rapid decline in labour intensity than other sub-sectors of manufacturing

** E.g. specialised process machinery and equipment for the FMCG industry are for example filling machines, food processing machines, packing equipment and palletising equipment (Processing & Packaging Machinery Association, 2016).*

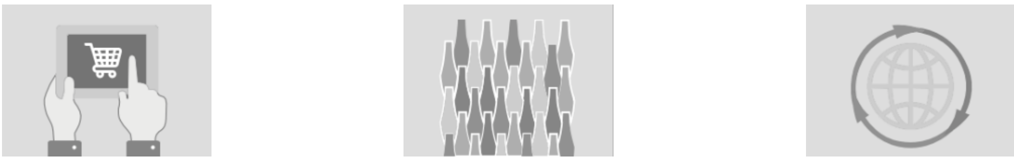
Table 1-3 - FMCG - Characteristics of general manufacturing environments and FMCG manufacturing environments (Processing & Packaging Machinery Association, 2016; Rhodes, 2014)

Machinery can be defined as the collection of machines that operate together to perform a task. Equipment can be defined as the necessary items for the purpose of the factory and its machinery (Processing & Packaging Machinery Association, 2016).

FMCG and Industry 4.0

The FMCG market can be characterised as a volatile market (Fry et al., 2017), which is continuously faced with changes as a result of megatrends, such as globalisation, technological developments and the internet driven connectivity at every level in society (Dobbs et al., 2016; Duivenvoorden, 2017; Odważny, Szymańska, & Cyplik, 2018). Mega trends are characterised as being global, forcing development and being transformational (United Nations, 2017).

The FMCG market is susceptible to trends, because of the pressure of consumer demands and the blurring boundaries between consumers and other actors in the value chain (Vacirca et al., 2014). The trends are affecting consumer demands, industry dynamics and external influences (Krings, Küpper, Schmid, & Thiel, 2016), such as individualisation of consumer demand, digitalisation of operations in the industry and tighter regulations externally (Figure 1-4).



Consumer demand, e.g.:
- Stagnating mass market
- Individualisation demand
- Continuously changing demand

Industry dynamics, e.g.:
- Integration value chain
- Digitisation of operations
- New business models

External influences e.g.:
- Tighter regulations carbon footprint and air discharges
- Higher shortage skilled workers

Figure 1-4 - FMCG - Trends affecting the FMCG market (Own figure, based on Krings, Küpper, Schmid, & Thiel, 2016)

The trends and expected changes influencing the FMCG market are assumed to directly influence the FMCG manufacturing industry. The manufacturing environments, i.e. the factories, and therefore also the construction projects of the factories, are also assumed to be influenced by the identified changes (Figure 1-5) (Küper et al., 2013).

Figure 1-5 - FMCG - Influences of trends in the FMCG market, the FMCG manufacturing industry and construction projects of FMCG factories (Own figure, based on Küper et al., 2013)

However, industrial construction projects often fail in terms of cost and time overruns, because of turbulent project environments, little front-end effort and high budget and schedule pressure (Merrow, 2011). Great benefits could be obtained for FMCG factories and the construction projects of FMCG factories, by implementing applications of Industry 4.0 (Breunig, Kelly, Mathis, & Wee, 2016). For FMCG factories, these benefits could for example include being able to cope with the continuous growth and changes. For the construction projects of FMCG factories, these benefits could for example include less cost and time overruns. Moreover, as stressed by Vacirca et al. (2014), not only benefits could be obtained, but risks may arise when the opportunities of Industry 4.0 are not exploited.

“Opportunities for FMCG companies prepared to radically reshape ... and clear risks for those who fail to.” (Vacirca et al., 2014, p. 2)

1.1.3 Construction Projects

Construction projects are characterised by their process and output (Hesham Hyari, 2005). The simplified process of a construction project consists of four phases: from the initiation phase to the exploitation and maintenance phase (
Figure 1-6). The two earliest phases in the process are also called the front-end phases (Lester, 2007).

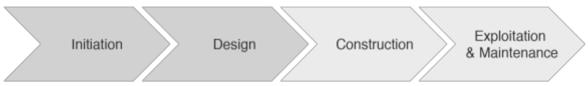


Figure 1-6 - Construction projects - Project phases (Own figure, based on Lester, 2007)

The output of a construction project is an immobile structure. For example, civil structures (e.g. bridges, dikes, etc.), buildings (e.g. houses, offices, etc.) or industrial buildings (e.g. factories, distribution centres, etc.) (Hesham Hyari, 2005).

Since the mid-20th century, common project drivers for construction projects have been time, cost and quality, within a fixed scope. Project drivers measure project success (Hesham Hyari, 2005). Time and cost can be seen as constrains, meaning projects should be on-schedule and in-budget. Quality can be seen as a goal, meaning projects should have a certain level of quality. Projects should have fixed scopes, meaning the boundaries of projects and the area of work of projects should be clear and do not change (Atkinson, 1999).

The management of organisation, information and the project drivers (i.e. time, cost, quality and fixed scope), is a well-known project control method in the construction industry (Figure 1-7) (Atkinson, 1999). This method generates control by managing all actors and stakeholders involved in the project (i.e. organisation), by managing the communication and the documentation of the project (i.e. information) and by managing the project drivers (Bektas, Lauche, & Wamelink, 2013; Leijten, 2016).

Figure 1-7 - Construction projects - Project drivers and project control aspects
(Own figure, based on Atkinson, 1999; Hesham Hyari, 2005)

Nowadays, projects are still being managed, based on these drivers and control aspects. However, already since the end of the 20th century, measuring on only four success criteria has been criticised (Atkinson, 1999; Hesham Hyari, 2005; Koolwijk & Vrijhoef, 2014; Toor & Ogunlana, 2010). Other success criteria, such as effectiveness, efficient use of resources and satisfaction of stakeholders, are said to become increasingly important. This implies that a broader view on project drivers would be desirable (Toor & Ogunlana, 2010).

The measuring on only four success criteria is one of the structural problems of the construction industry. Moreover, the construction industry has specific characteristics that make the industry way less productive than the manufacturing industry. For example, the labour productivity in construction has declined over the last decades, while manufacturing industries have doubled productivity (Oesterreich & Teuteberg, 2016). Characteristics of the construction industry which cause the low productivity of the industry are:

- *Complexity*: the large number of interactions and interdependencies of works and actors, at different stages and locations, make construction projects complex (Oesterreich & Teuteberg, 2016). Moreover, complexity is caused by the changing and unpredictable environment and the changing and/or incomplete specifications and requirements of projects (Dubois & Gadde, 2002). Complexity itself hinders innovation in the construction industry (Tatum, 1986).
- *Uncertainty*: the uncertain and unpredictable environments of construction projects lead to changing specifications and requirements of projects. These changes are defined as scope change (Sarde, Peth, Galli, & Katta, 2016). Scope change is seen as problematic by the project manager, because it often leads to time and cost overruns and lower quality (Nicholas & Steyn, 2012).
- *Front-end development*: the combination of the uncertainty in, and the importance of, the front-end phases of the process of construction projects contributes to the low productivity of the construction industry (Artto, Lehtonen, & Saranen, 2001). Important decisions phases (e.g. commitment of budget and planning) are made in the front-end phases based on assumptions instead of facts, because of the uncertain and unpredictable environments of construction projects. This can cause, for example, poor project budgeting and planning (Artto et al., 2001; Hesham Hyari, 2005).

Furthermore, the low productivity of the construction industry is caused by the structural problem of the relatively low investment in research and development in the construction industry (Hampson, Kraatz, & Sanchez, 2014). The low investment in research and development is caused by the following characteristics of actors in the construction industry (Oesterreich & Teuteberg, 2016):

- *Short-term thinking:* actors in construction projects operate as a loosely coupled system, only focusing on short-term projects, instead of long-term innovations and learnings.
- *Fragmented supply chain*: construction projects are characterised by a low rate of standardisation. Therefore, generally, a large number of different actors supply services and products in construction projects. This makes the supply chain in construction projects fragmented, hard to manage and unfit for the co-creation of innovations.
- *Culture:* actors in construction projects are well-known for actors being rigid and resistant to changes.

Construction projects and Industry 4.0

Although the strategy of Industry 4.0 is mainly focused on the manufacturing industry, the digital transformation is also changing the construction industry and therefore construction projects (Dallasega, Rauch, & Linder, 2018). However, the specific characteristics and structural problems of the construction industry described before, lead to the need for a different approach for reaching the potential of Industry 4.0 in the construction industry (Dallasega et al., 2018). The full potential of Industry 4.0 has not been reached yet. As Oesterreich and Teuteberg stated (2016, p. 137):

"Despite the given maturity and availability of many technologies, their widespread adoption by construction companies has not taken place until now."
(Oesterreich & Teuteberg, 2016, p. 137)

1.2 Research Gap

The research context, established in the last paragraph, provided the introduction to Industry 4.0, FMCG and construction projects. This paragraph introduces the research gap. The paragraph is divided into two sub paragraphs, presenting the scientific relevance (Paragraph 1.2.1) and the practical relevance (Paragraph 1.2.2) of this research. As Oesterreich and Teuteberg stated (2016, p.137):

"To move the innovative concept of Industry 4.0 in the complex environment of the construction industry towards new frontiers, further efforts in science and practice are needed." (Oesterreich & Teuteberg, 2016, p. 137)

1.2.1 Scientific Relevance

For this research, the combined knowledge fields of Industry 4.0, the FMCG manufacturing industry and construction projects are identified as research gap (Figure 1-8).

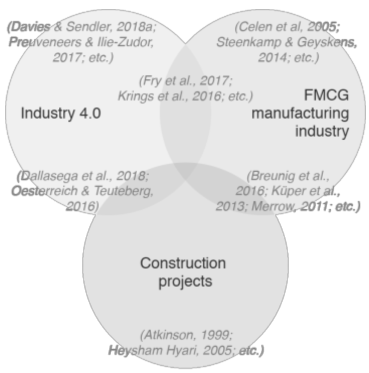


Figure 1-8 - Scientific relevance - Research gap - Combined knowledge fields (Own figure)

Before the 21st century, research concerning the FMCG manufacturing industry focused on the quick and flexible response to dynamic market conditions (Christy, 1993; Davis, 1989; Kotler, 1989). In the beginning of the 21st century research focused more on the dynamic demand side of consumers (Broekhuizen & Alsem, 2002; Gilmore & Pine, 2000; Michael & Richard, 2006). Currently, research focuses on Industry 4.0 solutions for smart manufacturing solutions for FMCG factories (Kolberg & Zühlke, 2015; Odważny et al., 2018; Preuveneers & Ilie-Zudor, 2017; Radziwon, Bilberg, Bogers, & Madsen, 2014; Zhou & Liu, 2016).

Current research also focuses on the far-reaching implications of the adoption of Industry 4.0 technologies in construction projects in general (Dallasega et al., 2018; Oesterreich & Teuteberg, 2016). However, since industrial construction projects are characterised as complex (Bosch-Rekveldt, Bakker, & Hertogh, 2017; Merrow, 2011), these specific types of construction project are assumed to need a different approach.

Based on the research gap identified, this research wants to contribute to knowledge on construction projects in the FMCG manufacturing industry within the context of Industry 4.0. Due to the explorative nature it is not aimed to close the research gap by conclusive evidence, rather to contribute knowledge.

1.2.2 Practical Relevance

This research was conducted in collaboration with Delft University of Technology and Royal HaskoningDHV (RHDHV). RHDHV operates as an engineering and project management consultancy company. As such, RHDV serves many different manufacturers in the FMCG manufacturing industry and has a lot of experience in construction projects of factories. RHDHV has noticed an interest of their clients in the FMCG manufacturing industry, to explore how the current output and process of construction projects in the FMCG industry are changing. Moreover, what could be the opportunities of Industry 4.0 related to these changes.

1.3 Thesis Structure

This thesis is divided into five parts, according to the five different phases of the research, which will be described in the research methodology (Paragraph 2.2). All parts are divided into different chapters (Figure 1-9). The first part, the research context, presents relevant background information for the rest of the thesis. The second, the research design, presents the design of the different data collection, data analysis and validation methods used for this research. The third part, the data collection, presents all data collected by the three different methods of data collection. The fourth part, the data analysis, presents the data analysis of all data collected. The fifth and last part, presents the result of the research.

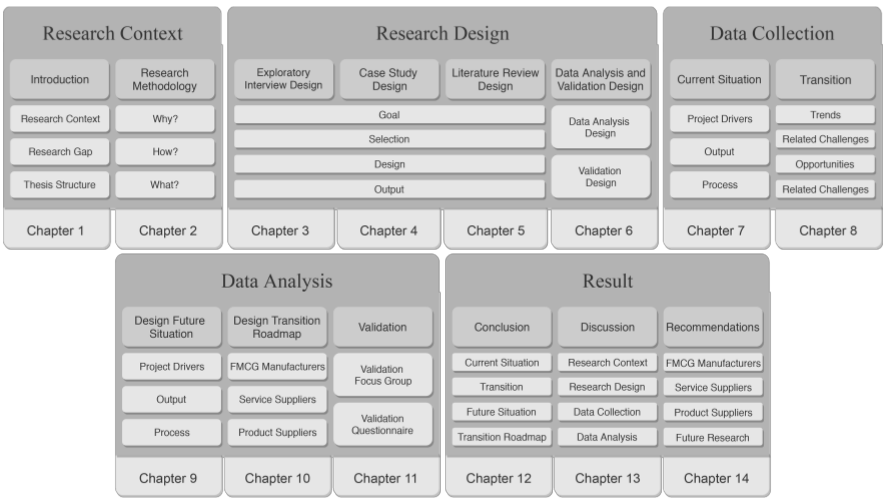


Figure 1-9 - Thesis structure (Own figure)

2

Research Methodology

This chapter presents the research methodology in three paragraphs. The first paragraph describes the research relevance (Paragraph 2.1). The second paragraph describes the research methodology (Paragraph 2.2) and in the third paragraph the research result is introduced (Paragraph 2.3).

2.1 Why? Research Relevance

This paragraph describes the research relevance. The paragraph is divided into four sub paragraphs. The first paragraph presents the problem definition (Paragraph 2.1.1). The second paragraph presents the scope of the research (Paragraph 2.1.2). The third paragraph presents the objective of the research (Paragraph 2.1.3) and in the fourth paragraph the research questions are presented (Paragraph 2.1.4).

2.1.1 Problem Definition

The dynamics (i.e. continuous growth and changes) within the FMCG manufacturing industry (Lafou, Mathieu, Pois, & Alochet, 2016) and the complexity of the construction projects (Oesterreich & Teuteberg, 2016) make construction projects in the FMCG manufacturing industry an interesting field of research, because of the tension and friction between the two knowledge fields (Vishal Jayram, 2001). Moreover, practical experience shows unsolved problems and unexploited opportunities in the current output and process of construction projects in the FMCG manufacturing industry.

Industry 4.0 is influencing both the FMCG manufacturing industry and construction projects. The influence of Industry 4.0 on the output and process of construction projects in the FMCG manufacturing industry is already significant and will be even more significant in the future, but is currently underexplored (Oesterreich & Teuteberg, 2016). The output and process of construction projects in the FMCG manufacturing industry therefore will be different in the future but are not yet ready for this future.

In short, the following problem statement is drawn:

Problem Statement
The output and process of construction projects in the FMCG manufacturing industry are not future-proof within the context of Industry 4.0.

Actors and Stakeholders

Related to the research context on FMCG (Paragraph 1.1.2), the value chain of FMCG (Figure 1-3) and the problem definition, the main actor and stakeholder roles related to construction projects in the FMCG manufacturing industry are identified. An actor is defined as a party that influences the project and has an interest in the project. A stakeholder is defined as a party that does not influence the project, but does have an interest in the project (Table 2-1) (Leijten, 2016).

Definitions party, actor, stakeholder		
Party	Party with specific authorities but not necessarily connected to the project. Party can be unconnected to the project, can be an actor, can be a stakeholder or can be both an actor and a stakeholder.	
Actor	Party that influences the project and has an interest in the process and/or output of the project.	
	Internal actor	Actor part of the project organisation.
	External actor	Actor not part the project organisation.
Stakeholder	Party that does not directly influence the project but does have an interest in the process and/or output of the project.	

Table 2-1 - Problem definition - Definitions of party, actor and stakeholder (Leijten, 2016)

Practical experience shows the main internal actors in construction projects in the FMCG industry are the FMCG manufacturers, divided into local and global departments, and the suppliers, subdivided into service and product suppliers. The FMCG manufacturers commissions (i.e. initiates) new factories and own and exploit existing factories. Governmental bodies can be defined as external actors, because they influence the project, but are not part of the project organisation. Consumers can be defined as main stakeholders, because they do not directly influence the project, but do have an interest in the project by having a four-dimensional demand for FMCG: specification, volume, moment and location (Table 2-2).

Actors and stakeholders	Division	Influence / Interest	Classification
FMCG manufacturer	Global department	Global initiator of construction projects of FMCG factories.	External actor
	Local department	Local initiator of construction projects of FMCG factories.	Internal actor
	Operational company (OpCo)	Exploits, i.e. operates, the existing FMCG factory and/or will operate the new FMCG factory in which raw materials are processed into consumer packaged goods.	Internal actor
Suppliers	Service suppliers	Supply services during process of construction projects, such as project management, construction management and consultancy.	Internal actors
	Civil product suppliers	Manufacture and supply civil products.	External actors
	Process product suppliers	Manufacture and supply machinery and equipment. I.e. original equipment manufacturer (OEM).	Internal / external actors
Governmental bodies		Approve environmental impact assessments (EIA) and building permits.	External actors
Consumers		Demand (i.e. specification, volume, moment and location) of goods.	Stakeholders

Table 2-2 - Problem definition - Actors and stakeholders (Based on practical experience)

With the identification of the main actors and stakeholders and the definition of their influence, interest and classification, an actor and stakeholder map is constructed (Figure 2-1). The identification and the definition of the actors and stakeholders are based on practical experience.

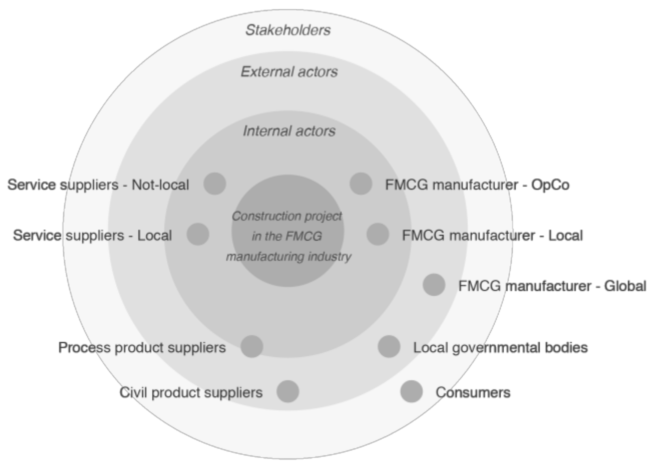


Figure 2-1 - Problem definition - Actor and stakeholder map (Own figure, based on practical experience)

2.1.2 Scope

The problem definition, established in the last paragraph, provided information on the problem and the actors and stakeholders related to the problem. This paragraph presents the definition of the scope. The paragraph is divided into the different dimensions on which the scope of this research is set.

Process and output of construction projects in the FMCG manufacturing industry

Since construction projects are characterised by their process and output (Paragraph 1.1.3) (Hesham Hyari, 2005), both the process and output of construction projects in the FMCG manufacturing industry are subject to this research. The process is defined as the phases from initiation to exploitation and the output is defined as a FMCG plant with a FMCG factory (Table 2-3). This dimension of the scope is set based on the assumption that the specific characteristics of the output, i.e. the FMCG factory, will influence the process of the construction projects.

Definitions of construction project, process and output in the context of this research	
Construction project	Project with a process from initiation to exploitation and an output of a built object.
Process of construction project in the FMCG manufacturing industry	Process from initiation to exploitation phase of construction project in the FMCG manufacturing industry.
Output of construction project in the FMCG manufacturing industry	FMCG plant with FMCG factory.

Table 2-3 - Scope - Definitions of construction project, process and output in the in context of this research

Green- and brownfield projects in the FMCG manufacturing industry

In the FMCG manufacturing industry, greenfield projects are new projects and brownfield projects are renovations, expansions, improvements, etc. (Vishal Jayram, 2001). Both types are considered in this research, based on the assumption that the process and output of green- and brownfield projects will be comparable.

Factory of FMCG manufacturer

FMCG manufacturers convert raw materials into consumer packaged goods, as established in the value chain of FMCG (Figure 1-3). Execution of this activity happens on a specific plant of a specific FMCG manufacturer. A plant can be defined as an asset of a business, including land and buildings. Plants can consist of multiple factories, distribution centres and other facilities. A factory can be defined as a building in which products and/or goods are manufacturers (American Industrial Works, 2018).

Construction projects can have an output of one or multiple of buildings. This research focuses on construction projects which consist of a manufacturing environment, i.e. the factory, as output. This dimension of the scope is set, based on the assumption that factories have different characteristics than other buildings on plants.

Multinational FMCG manufacturers

FMCG manufacturers are identified as main internal actors in construction projects in the FMCG industry (Figure 2-1) and are therefore considered to be occupied with the problem statement. In this research the construction projects of multinational FMCG manufacturers are taken into account, because it is assumed, projects of multinational FMCG manufacturers have similar characteristics and can therefore be compared. Additionally, it is assumed that projects of local FMCG manufacturers are subject to specific local circumstances to a higher extent, and therefore, harder to compare.

No geographical scope

Since the research scope is set on multinational FMCG manufacturers and it is assumed that specific local circumstances influence their projects to a lower extent than local FMCG manufacturers, no geographical scope is set. Moreover, practical experience shows FMCG manufacturers do not consider geographical boundaries, but only follow the consumer's demands. By reducing the importance and effect of national boundaries, multinational companies have tried to adopt a global management approach (Verter & Cemal Dincer, 1992).

Timespan until around 2030

Industry 4.0 was first introduced around 2010. The 1st and 2nd industrial revolutions were spaced more than one century apart, the 2nd and the 3rd were about 50 to 60 years apart and the 3rd and the 4th were only about 30 years apart (Preuveneers & Ilie-Zudor, 2017). Nowadays, developments follow each other at an even faster pace and therefore the timespan of Industry 4.0 is set on around 20 years. The timespan of this research is therefore set until around 2030.

2.1.3 Objective

Related to the problem statement, the following objective is formulated:

Objective

This research aims to future-proof the output and process of construction projects in the FMCG manufacturing industry within the context of Industry 4.0.

With this objective, the research aims at contributing to the research gaps identified (Paragraph 1.2). This research aims to explore the combined knowledge fields, i.e. the research gaps, through explorative researching. Due to the explorative nature of this research, it is aimed to contribute to the research gaps, rather than closing them.

For this research, a future-proof output and process in the context of Industry 4.0, is defined as the design of the output and process, so the opportunities of Industry 4.0 are embraced. Moreover, the research has been formulated so, that the designs can still be used in the uncertain future, even when new challenges, opportunities and transitions arise.

2.1.4 Research Questions

Based on the problem statement and the objective stated before, the following main research question (RQ) is formulated:

Research Question (RQ)

What can be done to future-proof the output and process of construction projects in the FMCG manufacturing industry within the context of Industry 4.0?

Within the research context (Paragraph 1.1), this research question concerns the current situation of construction projects in the FMCG manufacturing industry. Moreover, the transition due to trends and opportunities of Industry 4.0 is subject of this research and finally, also the future situation of construction projects in the FMCG manufacturing industry is subject of this research. The main research question combines all these research parts.

From the main actors and stakeholders identified (Paragraph 2.1.1), the internal actors, the FMCG manufacturer, the service suppliers and the process product suppliers, are considered to be the actionable parties related to the research question.

Sub research questions (SRQ's) are formulated to be able to answer the main research question and reach the research objective step by step. As input for the research questions, the first part of the research, the research context (Paragraph 1.1), is used.

The common project drivers for the process and output of construction projects are time, cost and quality, within a fixed scope (Figure 1-7) (Hesham Hyari, 2005). The first sub research question focuses on the common project drivers in the current situation of construction projects in the FMCG manufacturing industry specifically, to find the similarities and/or differences for this specific type of construction projects. The data collected on this sub research question can be found in paragraph 7.1

SRQ1 *What are the common **project drivers** in construction projects in the FMCG manufacturing industry currently?*

The second, third and fourth sub research questions focus on facts regarding the output of construction projects in the FMCG manufacturing industry, i.e. FMCG factories, currently. Based on the characteristics a classification of FMCG factories can be made. Based on the components and the spatial requirements similarities between different FMCG factories can be found. The data collected on these sub research questions can be found in paragraphs 7.2.1, 7.2.2 and 7.2.3.

SRQ2 *What are the common **characteristics** of FMCG factories currently?*
SRQ3 *What are the common **components** of FMCG factories currently?*
SRQ4 *What are the common **spatial requirements** of FMCG factories currently?*

The fifth sub research question focuses on the output of construction projects in the FMCG manufacturing industry, i.e. FMCG factories, currently. The data collected on this sub research question can be found in paragraph 7.2.4.

SRQ5 *What are the common **problems** of FMCG factories currently?*

The sixth, seventh and eighth sub research questions focus on the process of construction projects in the FMCG manufacturing industry currently. To fully understand the process of construction projects in the FMCG manufacturing industry currently, the sixth sub research question focuses on the phases and duration of the process. The project control aspects of organisation and information, of the well-known project control method in the construction industry (Figure 1-7) (Atkinson, 1999), form the basis for the seventh and eighth sub research questions. The data collected on these sub research questions can be found in paragraphs 7.3.1, 7.3.2 and 7.3.3.

SRQ6 *What are the common **phases and durations** in construction projects in the FMCG manufacturing industry currently?*
SRQ7 *What are the common **actors in the project organisation** in construction projects in the FMCG manufacturing industry currently?*
SRQ8 *What are the common **standards for information management** in construction projects in the FMCG manufacturing industry currently?*

The ninth sub research question focuses on the process of construction projects in the FMCG manufacturing industry currently. The data collected on this sub research question can be found in paragraph 7.3.4.

SRQ9 *What are the common **problems** of the process of construction projects in the FMCG manufacturing industry currently?*

The tenth and eleventh sub research questions focus on the trends influencing the FMCG manufacturing industry and challenges as result of the trends. The data collected on these sub research questions can be found in paragraphs 8.1 and 8.2.

SRQ10 *What are the **trends** influencing the FMCG manufacturing industry?*
SRQ11 *What are the **challenges** as the result of the **trends**?*

The twelfth and thirteenth sub research questions focus on the opportunities and challenges as result of the opportunities of Industry 4.0, related to the trends and challenges influencing the FMCG manufacturing industry. The data collected on these sub research questions can be found in paragraphs 8.3 and 8.4.

SRQ12 *What are the **opportunities of Industry 4.0** related to the trends and challenges influencing the FMCG manufacturing industry?*
SRQ13 *What are the **challenges** as the result of the **opportunities of Industry 4.0**?*

The fourteenth sub research question focuses on the project drivers in the future situation for the process and output of construction projects in the FMCG manufacturing industry. The data collected on this sub research question can be found in 0.

SRQ14 *What could be the common **project drivers** in construction projects in the FMCG manufacturing industry in the future?*

The fifteenth and sixteenth sub research questions focus on the output of construction projects in the FMCG manufacturing industry in the future. The data analysis done to answer these sub research questions can be found in 9.2

SRQ15 *What could be the **technologies** of Industry 4.0 influencing the **output** of construction projects in the FMCG manufacturing industry?*
SRQ16 *What could the **output** of construction projects in the FMCG manufacturing industry look like in the future?*

Finally, the seventeenth and eighteenth sub research questions focus on the process of construction projects in the FMCG manufacturing industry in the future. The data analysis done to answer these sub research questions can be found in paragraph 9.3.

SRQ17 *What could be the **technologies** of Industry 4.0 influencing the **process** of construction projects in the FMCG manufacturing industry?*
SRQ18 *What could the **process** of construction projects in the FMCG manufacturing industry look like in the future?*

What the output and process of construction projects in the FMCG manufacturing industry could like in the future relates to the objective of the research: a future-proof output and process in the context of Industry 4.0.

All research questions are related to a different part of the research. The different parts of the research are divided into the output and process of construction projects and divided into the current situation, the transition towards the future situation and the future situation (Figure 2-2).

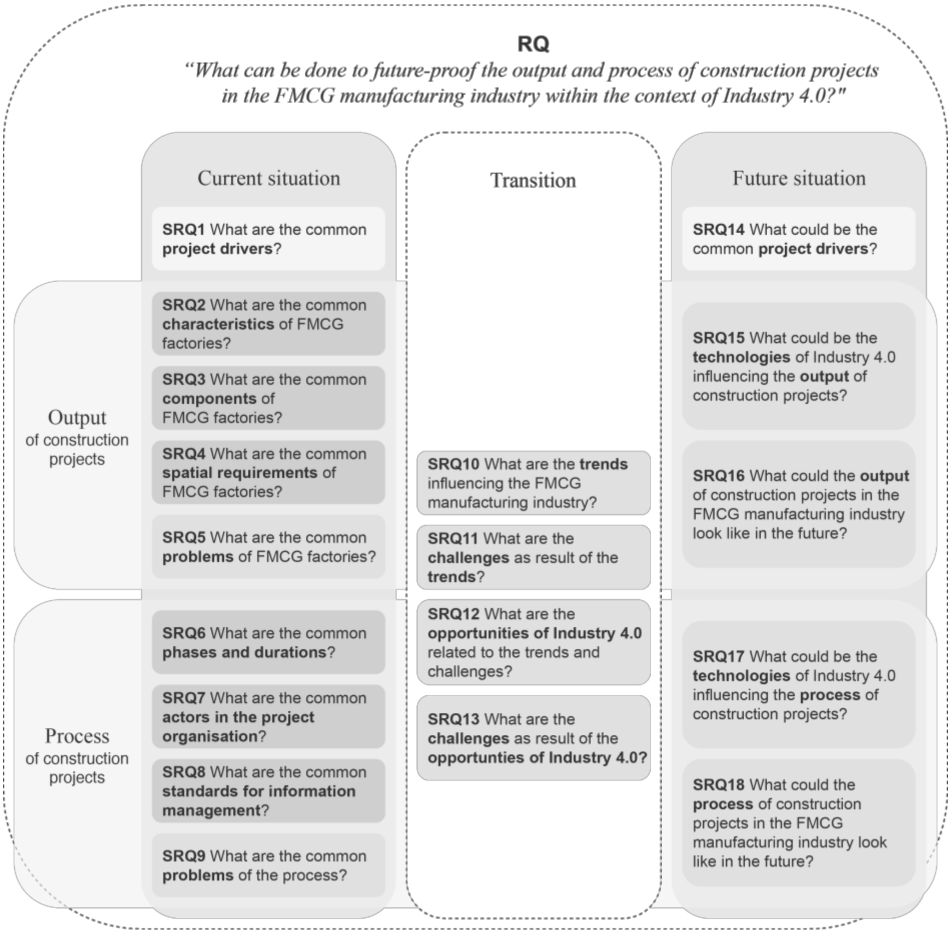


Figure 2-2 - Research questions (Own figure)

All concepts used in the research questions are operationalised (i.e. defining the indicators for measuring the concepts) in the part of the research design and in the part of the data collection.

2.2 How? Research Methodology

This paragraph describes the research methodology. The research methodology is divided into five main phases, in order to reach the objective and answer the main and sub research questions in the last phase (Figure 2-3).

Figure 2-3 - Research methodology - Phases (Own figure)

In the first phase, the research context, the context for this research is established and the research gap is identified. In the second phase, the research design, the design for the different data collection methods and the data analysis and validation are made. In the third phase, the data is collected through the different data collection methods. In the fourth phase, the data is analysed and validated and in the fifth and last phase, the research result is made.

Data Collection

Related to the different parts of the research and the sub research questions related to these parts, the data collection steps are defined (Figure 2-4). The order of these steps is related to the order of the sub research questions.

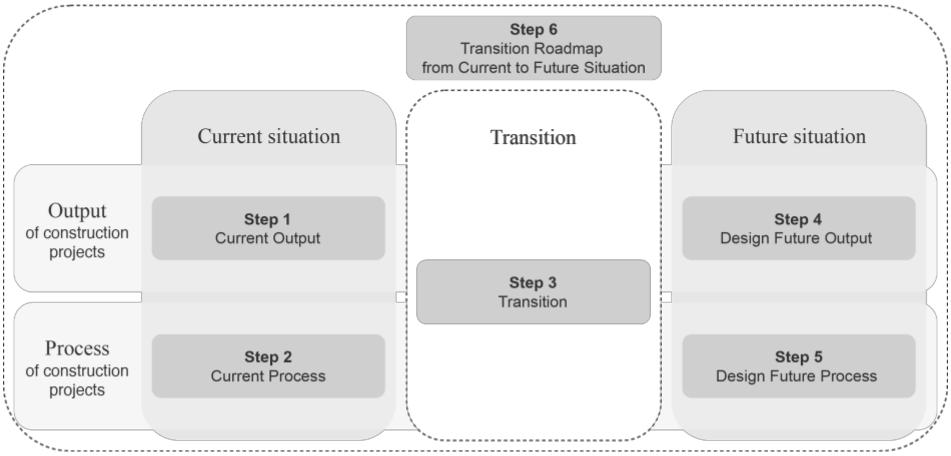


Figure 2-4 - Research methodology - Data collection steps (Own figure)

Related to the different research steps, different data collection methods are defined (Figure 2-5). In the first and second step, the research aims to describe the generalities of the output and process of construction projects in the FMCG industry and identify the key problems, based on exploratory interviews, a multiple-case study and a literature review. In the third step, the research aims to give more information on the trends and challenges of the transition and the opportunities and challenges of Industry 4.0 related to the transition, based on a literature review. In the fourth and fifth, the research aims to describe a more future-proof output and process of construction projects in the FMCG industry, by making an output typology and process roadmap, respectively. Finally, in the sixth step, the research aims to combine and analyse all above named information, to design a transition roadmap from the current to the future situation.

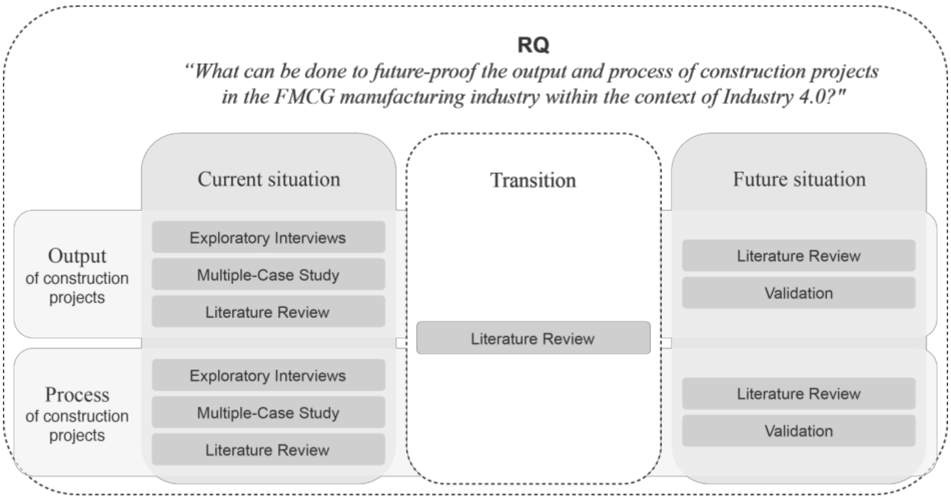


Figure 2-5 - Research methodology - Data collection methods (Own figure)

With all three data collection methods both qualitative and quantitative data is collected. Qualitative data is used to gain understanding of underlying reasons, opinions and motivations. Quantitative data is used to quantify the problem by a way of generating measurable data on opinions and/or facts. For qualitative data, operationalisation takes place when topics are selected to gather observations. In quantitative research, operationalisation takes place by selecting indicators for the translation of observations into measurements (Verschuren & Doorewaard, 2013).

In the next part of this thesis, the research design, the design of the three different data collection methods will be further explained: the exploratory interviews (Chapter 3), the multiple-case study (Chapter 4) and the literature review (Chapter 5).

Data Analysis and Validation

To be able to perform the data analysis on all data collected by the different methods, a framework of different levels for the data collection was made (Figure 2-5). The research is about a specific type of construction projects and makes use of a multiple-case study. Therefore, general construction projects are compared to the specific type of the construction projects, to find similarities and differences. From general construction projects, to construction projects of a specific FMCG manufacturer, to individual case study projects. The data analysis design will be further explained in the research design part of this thesis (Paragraph 6.1).

Figure 2-6 - Research methodology - Data analysis - Levels of data collection (Own figure)

To assure the validity of the research, both external and internal validity are taken into account. External validity is the strategic sampling of data and results (Verschuren & Doorewaard, 2013), for which the interviewees, case study projects and concepts are strategically chosen.

Internal validity is the triangulation of sources, i.e. using different data collection methods, to substantiate results (Yin, 2012). Observations from multiple interviews with people from different actors, with different perspectives, are compared. A multiple-case study is done in which observations from different projects are compared. Moreover, the findings from interviews and the multiple-case study are compared to findings in literature.

Furthermore, validation of the data analysis is done by using a validation focus group and a validation questionnaire. The validation design of the focus group and questionnaire will be further explained in the research design part of this thesis (Paragraph 6.2).

2.3 What? Research Result

This paragraph introduces the research result. The research is conducted in the context of Industry 4.0. This research field is quite novel, since Industry 4.0 was first named in 2013 (Davies & Sendler, 2018a). Moreover, no previous research has been done in the exact knowledge field of construction projects in the FMCG manufacturing industry. Therefore, an exploratory research is conducted. Due to the exploratory nature of this research, it is not intended to provide conclusive evidence, but instead, it is intended to explore the research field and create better understanding of the research context.

The research result is related to the research context (Paragraph 1.1), the problem statement (Paragraph 2.1.1), the objective (Paragraph 2.1.3) and the main research question (Paragraph 2.1.4). To future-proof the process and output of construction projects in the FMCG manufacturing industry within the context of Industry 4.0, a transition roadmap from the current to the future situation is constructed.

The aim of the transition roadmap is to enhance the opportunities of Industry 4.0 and providing solutions related to challenges caused by trends for the future output and process of construction projects in the FMCG manufacturing industry. The three actionable actors, related to the main research question are the FMCG manufacturer, the service suppliers and the process product supplier. The transition roadmap will present different specific steps and recommendations for the three different actors.

Research Design

Chapter 3 *Exploratory Interview Design*
Chapter 4 *Case Study Design*
Chapter 5 *Literature Review Design*
Chapter 6 *Data Analysis and Validation Design*

(Picture Royal HaskoningDHV, case study project 2B in Vietnam)

Research Design

The second part of this thesis, the research design, presents the design of the different data collection, data analysis and validation methods used for this research, in four chapters. The first chapter presents the exploratory interview design (Chapter 3). The second chapter presents the case study design (Chapter 4). The third chapter presents the literature review design (Chapter 5) and in the fourth chapter the data analysis and validation design are presented (Chapter 6).

3

Exploratory Interview Design

This chapter presents the exploratory interview design. Exploratory interviews are used as data collection method for the current situation. The chapter is divided into five paragraphs, describing the goal (Paragraph 3.1), the interviewee selection (Paragraph 3.2), the interview design (Paragraph 3.3) and the output (Paragraph 3.4) of the exploratory interviews.

3.1 Exploratory Interview Goal

In line with the exploratory nature of this research, exploratory interviews are used to gain the first insights in the current output and process of construction projects in the FMCG manufacturing industry. The levels of data collected with the exploratory interviews are general construction projects and construction projects in the FMCG manufacturing industry (Figure 3-1).

Figure 3-1 - Exploratory interview goal - Levels of data collection exploratory interviews (Own figure)

In general, interviews involve people, an interviewer and interviewee(s), exchanging information through questions and answers by an in-person meeting. Semi-structured interviews are said to be a suitable starting point for research projects, because interviewees are given the opportunities to share information with the researcher from their own perspective and in their own words. Rather than being asked to fit those perspectives into the, perhaps limited, view of the researcher. Interviews are most often used for qualitative data collection (Verschuren & Doorewaard, 2013).

Since exploratory interviews are a suitable method for gaining the first insights, the goal of the exploratory interviews is to collect the first qualitative and quantitative data on general construction projects and construction projects in the FMCG manufacturing industry. With these insights, the goal is to further define the exact scope of the research.

3.2 Exploratory Interviewee Selection

To reach the goal of the exploratory interviews, specific interviewee selection criteria for the exploratory interviews are set. These criteria are set to be able to compare the data collected, so data analysis (i.e. cross-expert analysis) can be done and general findings from the exploratory interviews can be presented. The criteria are related to the scope (Paragraph 2.1.2) and objective (Paragraph 2.1.3) of the research.

The exploratory study interviewee selection is done based on the following criteria, which will further be explained:

- High level of experience in construction projects in the FMCG manufacturing industry
- Experience from a service supplier perspective in the FMCG manufacturing industry
- Variation in construction projects in which the interviewee has experience
- Variation in project phases in which the interviewee has experience
- Variation in roles within the project organisation

- **High level of experience**

Since the interviewees are given the opportunity to share information form their own perspective, it is desirable the interviewees have a high level of experience on which their perspective is based. Moreover, responses substantiated by practical examples are valuable. A high level of experience is considered to be working on multiple (i.e. more than one) construction projects in the specific industry.

- **Experience from a service supplier perspective**

Generally, the service supplier has a central role in the project organisation of construction projects, because information from all other actors in the project organisation is needed for the service supplier to deliver its service. Moreover, the service supplier often manages other actors within the project organisation. For the first step in understanding construction projects in the FMCG manufacturing industry, its therefore chosen to select interviewees with this perspective.

- **Variation in construction projects**

With regards to triangulation of sources, the group of interviewees should have a variation in construction projects in which the interviewees have experience. Different projects have different characteristics. Commonalities between the experiences of people in different projects can lead to general observations, instead only project-specific observations.

- **Variation in project phases**

Since different project phases consist of different steps, milestones, actors involved, problems, opportunities, etc. and generally, people do not have experience in all project phases, the group of interviewees needs to cover all different project phases.

- **Variation in roles**

From a service supplier perspective, different roles operate in different project phases. Therefore, the variation in project phases should automatically also lead to a variation in roles. Moreover, within project phases also a variation in roles can be made. The different perspectives of different roles, from a more generic to a specific perspective, are assumed to generate different insights.

In appendix A, the exploratory interviewees (Table A-1) and the exploratory interview framework (Table A-2) can be found.

3.3 Exploratory Interview Design

In this paragraph the steps taken, the tools used, and the limitations of the exploratory interviews are described.

After selection and invitation of the interviewees by sending them a short introduction on the researcher, the research and the goal of the interview, all exploratory interviews were conducted face-to-face and were recorded (with permission of the interviewee). The recording of the interview should lead to focus on the interaction rather than documenting everything that is being said. The face-to-face nature of the interviews helps to better understanding between the interviewee and researcher and helps to interpret the interviewee's responses (Verschuren & Doorewaard, 2013).

The exploratory interviews were conducted in a semi-structured way, without interview guide, but with a list of themes to be discussed. It was more important to gain insights on the perspectives of the interviewee than asking very specific questions, since the exploratory interviews were the first step in collecting data. Moreover, in the phase wherein the exploratory interviews were conducted, the exact scope of the research was not clear yet and had to be defined whilst conducting the exploratory interviews.

After each interview a summary of the interview was made based on the recording. The summary was sent to the interviewee for control to avoid misinterpretations of the recording by the researcher. Since the exploratory interviews were done by using a list of themes to be discussed, a thematic analysis on the redacted summaries of the interviews was done. This widely-used qualitative data analysis method is used to identify patterned meaning across all data (Creswell, 2007). Although the interviews were mainly focused on collecting opinions from different perspectives, it was important to make a distinction between opinions and facts (Verschuren & Doorewaard, 2013). Moreover, for opinions a division was made into perspectives, causes and consequence. Subsequently, the consequences were subdivided into negative and positive (Table 3-1). The thematic analysis of the redacted summaries of the interviews were eventually used as empirical data.

Opinions			Facts
• Perspectives			• Themes
• Causes	• Consequences		o Sub themes
	o Negative Problems and challenges	o Positive Solutions and opportunities	

Table 3-1 - Exploratory interview design - Subdivision of opinions and facts in data collection

Limitations

The data collection by, and data analysis, of interviews are argued to have common limitations. The reliance on the interviewees accuracy is a argued to be a limitation regarding the data collection (Bogner, Littig, & Menz, 2009). For the data analysis of data collected by interviews the following common limitations can be argued (Verschuren & Doorewaard, 2013):

- The interviewer has the tendency to ignore conflicting information
- The interviewer has the tendency to emphasise on information that confirms assumptions, rather than the other way around
- The interviewer has the tendency to ignore information that is hard to gain

By the selection of the interviewees on the criteria named before and the invitation upfront introducing the research and goal of the interview, it is tried to minimise the risk of the limited accuracy of the interviewee. Moreover, by summarising the interviews based on recordings, instead of the interviewer's notes, it is tried to minimise the risk of the tendencies to ignore or emphasise certain information. Finally, by sending the summaries to the interviewees for control, it is tried to minimise the impact of the interviewer on the redacted summaries, which are used as empirical data.

3.4 Exploratory Interview Output

In total, eight exploratory interviews were conducted with eight different people. Summaries of the exploratory interviews can be requested from the author of this thesis. This paragraph describes the output (i.e. data collected) of the exploratory interviews.

Data was collected on the current process and output of general construction projects and construction projects in the FMCG manufacturing industry (Figure 3-1). The themes on which data was collected is related to the themes of the sub research questions (Paragraph 2.1.4). Through the exploratory interviews, data was collected, on the following specific themes:

- Project drivers
- Phases and durations of the process
- Organisation and information in the process
- Problems of both the output and the process

In appendix C.1, data collected by the exploratory interviews on the process of construction projects in general (Table C-1), on the process of construction projects in the FMCG manufacturing industry (Table C-2) and the key take-aways (Table C-3), all from the service supplier perspective, can be found. The observations from the exploratory interviews are paraphrased throughout the main text of this report. Moreover, the comparison of observations of all exploratory interviewees are used as qualitative data and can be found in tables throughout the main text of this report.

4

Case Study Design

This chapter presents the case study design. The multiple-case study is used as data collection method for the current situation. The chapter is divided into five paragraphs, describing the goal (Paragraph 4.1), the case study project and interviewee selection (Paragraph 4.2), the case study design (Paragraph 4.3) and the output (Paragraph 4.4) of the multiple-case study.

4.1 Case Study Goal

The multiple-case study is used to gain in-depth insights in the current output and process of construction projects in the FMCG manufacturing industry. The levels of data collected with the multiple-case study are construction projects in the FMCG manufacturing industry, construction projects of a specific FMCG manufacturer and the individual case study projects (Figure 4-1).

Figure 4-1 - Case study goal - Levels of data collection (Own figure)

A case study is a type of field research and generally consist of data collection through a project documentation and case study interviews. A case study is characterised by intensive data generation and therefore generally one or a small number of research units is used. For this research five research units, i.e. construction projects, are used. A case study is said to be suitable for data collection of both qualitative and quantitative data. Moreover, a case study is generally used to gain in-depth rather than breath insights on the research units (Verschuren & Doorewaard, 2013).

Since a multiple-case study is a suitable method for gaining in-depth insights, the goal of the multiple-case study is to collect in-depth qualitative and quantitative data on construction projects in the FMGCG manufacturing industry.

4.2 Case Study Project and Interviewee Selection

This paragraph is divided into two sub paragraphs. The first paragraph describes the case study project selection (Paragraph 4.2.1) and in the second paragraph the case study interviewee selection is described (Paragraph 4.2.2).

A comparative case study research method is used, which means multiple projects (i.e. research units) are selected to eventually be compared (Verschuren & Doorewaard, 2013). Moreover, case study interviews are conducted with multiple project actors from different perspectives (Yin, 2012). Therefore, both case study project selection and case study interviewee selection criteria are set to be able to compare the data collected. On which, eventually, data analysis (i.e. cross-case analysis) is done to generate general findings from the multiple-case study.

4.2.1 Case Study Project Selection

The case study project selection criteria are related to the scope of the research (Paragraph 2.1.2). The case study project selection is done based on the following criteria, which will further be explained:

- Green- or brownfield project of FMCG manufacturer
- Factory of FMCG manufacturer
- Multinational FMCG manufacturer (global / local characteristics)

- **Green- or brownfield project of FMCG manufacturer**

Since the scope of the research (Paragraph 2.1.2) is focused on construction projects in the FMCG manufacturing industry, all case study projects are required to be of this type. Based on practical experience, it is assumed that the output, the FMCG factory, and the process, of green- and brownfield projects will be comparable. This is assumption is made, because the objective of this research does not make a differentiation between green- and brownfield projects, because no clear indicators show one of the two is more related to the problem statement. However, this assumption could be subject to future research.

- **Factory of FMCG manufacturer**

Since the research scope (Paragraph 2.1.2) is set on a specific output of construction projects in the FMCG manufacturing industry, the case study should have an output which consists of a manufacturing environment, i.e. a factory.

- **Multinational FMCG manufacturer**

Since this research has no geographical scope (Paragraph 2.1.2), the projects used should be initiated by multinational FMCG manufacturers. This makes the findings less subject to specific local circumstances and more general and international conclusions can be drawn for construction projects in the FMCG manufacturing industry.

Moreover, five more practical selection criteria are formulated:

- Involvement of RHDHV in project as consultant and/or project manager
- Involvement of RHDHV in project during initiation and/or design phases
- Start of project not before 2008 (10 years ago)
- Project documentation at least contains: contact persons, budget, schedule
- Contact person of case available for interview about case

Since the practical selection criteria are straight forward, these will not be explained further.

Since a multiple-case study is conducted, differentiation criteria between projects are formulated, to make sure the case study results are not too specific and eventually general conclusions can be drawn:

- Differentiation between green- and brownfield projects
- Differentiation between finished and ongoing projects
- Differentiation in geographical locations of projects
- Differentiation in FMCG manufacturers of projects

- **Differentiation between green- and brownfield projects**

In this research, it is not aimed to test the assumption of comparable green- and brownfield projects. However, the results of the multiple-case study with a differentiation in green- and brownfield projects can be the used as a start to test the assumption in future research.

- **Differentiation between finished and ongoing projects**

A distinction between finished and ongoing projects is made, to be able to research the finished output of the projects and on the other hand, to be able to research the most recent representation of the process of construction projects in the FMGC manufacturing industry.

- **Differentiation in geographical locations of projects**

A differentiation in the geographical location of projects is set as a criterium, related to the absence of a geographical scope of this research and the criterium of multinational FMCG manufacturers. This criterium is set for the findings to be less subject to specific local circumstances.

- **Differentiation in FMCG manufacturers of projects**

Since this research aims to draw general conclusions for construction projects in the FMCG manufacturing industry, a differentiation in FMCG manufacturers initiating the projects is made. For this research, it is assumed that the output and the process of projects of different FMCG manufacturers will be comparable. This makes the findings less subject to a specific FMCG manufacturer. However, this assumption could be subject to future research.

In appendix B.1, the selected case study projects (Table B-1) can be found.

4.2.2 Case Study Interviewee Selection

Moreover, specific case study interviewee selection criteria for the case study interviews are set. These criteria are related to the scope (Paragraph 2.1.2) and objective (Paragraph 2.1.3) of the research. The case study interviewee selection is done based on the following criteria, which will further be explained:

- Experience in a case study project
- Project manager per case study project
- Differentiation in perspectives per the case study project

- **Experience in a case study project**

Since the goal of the multiple-case study is to collect data on individual case study projects and draw general conclusion by comparing the data collected on the different projects, the case study interviewees should have experience in at least one of the case study projects.

- **Project manager per case study project**

Since the project organisation of each case study consists of many different actors, consisting of many different roles, and due to time constrains, it is impossible to interview all actors and all roles. The project manager usually is in the centre of the project organisation and therefore has the most holistic overview of the project (Leijten, 2016). Therefore, for each actor interviewed, at least the role of project manager should be interviewed.

- **Differentiation in perspectives per the case study project**

For each case study project, actors from different perspectives should be interviewed. Because interviews are suitable for gathering qualitative data (e.g. opinions, motivations, etc.) (Verschuren & Doorewaard, 2013), it is valuable to get these observations from different perspectives.

In appendix B.2, the case study interviewees (Table B-2, B-4, B-6) and the case study interview frameworks (Table B-3, B-5, B-7, B-8) can be found.

4.3 Case Study Design

In this paragraph the steps taken, the tools used and the limitations of the multiple-case study are described.

The multiple-case study is done in two steps. Firstly, the collection of project documentation is used to create the first understanding of the project and to collect the documented data on the project. Secondly, the case study interviews are used to create deeper understanding of the project and to collect data on facts and opinions of actors with different perspectives on the project. The data collected on all projects in both steps is compared in the data analysis.

Data Collection Project Documentation

Firstly, data was collected on the FMCG manufacturers, using their annual reports as documentation. Secondly, data was collected on the individual case study projects, using the following documentation:

- Bidding and documents
- Budgets and costs documents
- Change orders and change overviews
- Contracts
- Design drawings
- Organisational structures
- Project data books
- Project photo’s
- Progress reports and meetings
- Project schedules and planning
- Proposals
- Technical data

The data collected through project documentation is used as factual empirical data.

Data Collection Case Study Interviews

The case study interviews were partly conducted face-to-face and partly through Skype. With permission of the interviewee, the face-to-face interviews were recorded. During the interviews through Skype written records were made.

The case study interviews are conducted in a semi-structured way, using an interview guide. An example of an applied interview guide can be found in appendix B.1 (Table B-9). An interview guide is a list of themes or questions to be (partly) covered during the interview. Usually, most of the questions are open-ended, to avoid phrasing the question in a leading way (Verschuren & Doorewaard, 2013).

All interviews started with an introduction of the interviewee, the researcher and the research, followed by discussing the interview guide. Since the case study interviews were done with people looking to the projects from different perspectives, it was more important to gain insights on their perspectives on the project than on the facts of the project. After each interview a summary of the interview was made on the basis of the recording or records. The summary was sent to the interviewee for control to avoid misinterpretations of the recording by the researcher. The redacted summaries of the interviews were eventually used as empirical data.

Limitations

A case study is argued to have multiple common limitations (Verschuren & Doorewaard, 2013):

- Lack of breadth: detailed information from a very small number of case study projects
- Hard to compare: due to different characteristics of case study projects, data may be hard to compare

Through the differentiating selection criteria for the case study projects, it is tried to resolve the limitation of the lack of breadth. Moreover, through the other selection criteria, it is tried to resolve the limitation of the difficulty of comparing the case study projects, since with these criteria a certain scope is set.

4.4 Case Study Output

Five projects were researched from three different FMCG manufacturers. Project documentation was collected, and 14 case study interviews were done with 15 different people. For each project the FMCG manufacturer and service supplier in the project organisations were interviewed. One process product supplier (i.e. original equipment manufacturer (OEM)) was interviewed, related to the case study projects of two FMCG manufacturers (Figure 4-2). Summaries of the case study interviews can be requested from the author of this thesis.

Figure 4-2 - Case study output (Own figure)

Data was collected on the current process and output of construction projects in the FMCG manufacturing industry to individual case study projects (Figure 4-1). The themes by which data was collected is related to the themes of the sub research questions (Paragraph 2.1.4).

Through the multiple-case study, to the following specific themes data was collected:

- Project drivers
- Characteristics, components and spatial requirements of the output
- Phases and durations of the process
- Organisation and information in the process
- Problems of both the output and the process

In appendix D, data collected by the multiple-case study can be found: data of the FMCG manufacturers (D.1), general data of the projects (D.2), output data of the projects (D.3) and process data of the projects (D.4). The observations from the multiple-case study are paraphrased throughout the main text of this report. Moreover, the comparison of observations of all case study projects are used as qualitative data and can be found in tables throughout the main text of this report and the appendices.

5

Literature Review Design

This chapter presents the literature review design. The literature review is used as data collection method for the current situation and the transition. The chapter is divided into three paragraphs, describing the goal (Paragraph 5.1), the concept selection (Paragraph 5.2), the literature review design (Paragraph 5.3) and the output (Paragraph 5.4) of the literature review.

5.1 Literature Review Goal

The literature review is used to gain insights in the current output and process of construction projects. The levels of data collected in the literature review are general construction projects, construction projects in industry and construction projects in the manufacturing industry (
Figure 5-1).

Figure 5-1 - Literature review goal - Levels of data collection (Own figure)

Moreover, the literature review is used to gain insights in the trends influencing the FMCG manufacturing industry and the opportunities of Industry 4.0 related to the trends.

Generally, a literature review is used to give a recent and structured overview of the literature in the research field (Verschuren & Doorewaard, 2013). Literature on the specific combined research fields of this research is limited and therefore this data collection method focused on the more general levels of data.

The goal of the literature review is to collect qualitative facts on general construction projects, construction projects in general industry and construction projects in the manufacturing industry. Eventually, to be able to compare the findings from the exploratory interviews and the multiple-case study with findings from literature in the data analysis phase. Moreover, the goal of the literature review is to collect all information needed on the trends influencing the FMCG manufacturing industry and the opportunities of Industry 4.0 related to the trends.

5.2 Concept Selection

Concepts are an abstraction of reality and can capture both opinions and facts (Watt & Van den Berg, 2002). The selection of concepts subject to the literature review is made based on the research questions (Paragraph 2.1.4) and based on the findings from the exploratory interviews. From the exploratory interviews the output is already established (Paragraph 3.4) and the findings will be presented in the data collected on the current situation (Chapter 7) in the data collection part of this thesis. The concepts identified in this paragraph (Table 5-1), will be defined and operationalised in the data collection part of this thesis. The definition and operationalisation will be described in the literature review design (Paragraph 5.3).

Concepts related to current output	Concepts related to current process	Concepts related to transition	Concepts from findings exploratory interviews
• Project drivers • Characteristics • Components • Spatial requirements • Problems of output • Project drivers	• Organisation and actors in the project organisation • Information and standards for information management • Problems of process	• Trends • Industry 4.0 • Opportunities • Challenges	• Changeability • Integration

Table 5-1 - Concept selection - Identification of concepts

5.3 Literature Review Design

This paragraph describes the steps taken for the literature review. Firstly, the concepts subject to the literature review were defined and operationalised. Secondly, a systematic search on both scientific and management literature related to the concepts was done. Thirdly, a review on the literature found and a thematic analysis on the review was done to be able to compare the findings from the exploratory interviews and the multiple-case study to the findings in literature.

In theory-oriented research, the definitions of concepts given in literature are mostly perfectly useful. Whereas in practice-oriented research, the definitions given in literature usually need further elaboration as these are too general and/or too complex (Verschuren & Doorewaard, 2013). For this research, the concepts are put in context by linking them to the research objective. Moreover, the concepts that need further elaboration are defined based on combining the findings from practice and literature.

Operationalising is the process of choosing and describing the indicators for measurement of the concepts. Moreover, it entails determining the values of these indicators. This results in an operational definition (Verschuren & Doorewaard, 2013). The operational definitions are used to compare the findings from the exploratory interviews, the multiple-case study and the literature review and draw conclusions from these combined findings. The operational definitions can be found in the next part of the thesis, the data collection. Related to both the current situation (Chapter 7) and the transition (Chapter 8).

5.4 Literature Review Output

Data was collected on the current process and output of general construction projects to construction projects in the manufacturing industry (
Figure 5-1). The themes on which data was collected are related to the themes of the sub research questions (Paragraph 2.1.4). Through the literature review, the specific themes on which data was collected are the concepts related to the current situation and the transition (Table 5-1). The observations from the literature review are paraphrased throughout the main text and appendices of this report.

In appendix E, the data collected on the current situation by the literature review can be found and in appendix G, the data collected on the transition by the literature review can be found.

6
Data Analysis and Validation Design

This chapter presents the data analysis and validation design in two paragraphs. The first paragraph describes the data analysis design (Paragraph 6.1) and in the second paragraph the validation design is described (Paragraph 6.2).

6.1 Data Analysis Design

After the data collection through the three different methods, all collected data will be analysed. The data analysis is about structuring the data from each data collection method and combining the structured data to find patterns in similarities and differences in the observations (Bryman, 2006).

The structuring of data from each data collection method is done with three different types of cross-analyses: cross-expert analysis, cross-case analysis and cross-concept analysis. The combining of data from the three data collection methods is done by a continuous loop between top-down and bottom-up approach. From general to specific data and the other way around.

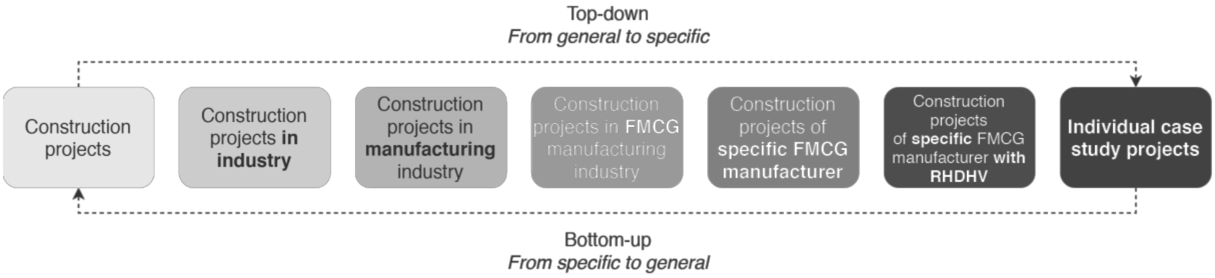


Figure 6-1 - Data analysis design - Top-down and bottom-up approach (Own figure)

A cross-expert analysis is the comparison of different expert observations (Creswell, 2007). In this research, the observations from experts were collected by exploratory interviews and case study interviews. The thematic analyses of the observations of all interviews, described in the exploratory interview design (Paragraph 3.3), were compared. Both qualitative

A cross-case analysis is the comparison of observations from different case study projects (Creswell, 2007). In this research, the observations from documentation and interviews of five different projects were collected and compared.

A cross-concept analysis is the comparison of different concepts identified, defined and operationalised by a literature review (Creswell, 2007). This research is a combination between theory-oriented and practice-oriented research, for which the definition of the concepts researched is done based on findings from literature and practice. Different types of relations between concepts can be distinguished (Watt & Van den Berg, 2002):

- Null relationships: concepts are not related in any way and are therefore completely independent.
- Covariance relationships: concepts are associated with each other, but a change in one concept does not necessarily lead to a change in the other concept.
- Causal relationships: concepts are cause-effect related, a change in one concept (the cause), leads to a change in the other concept (the effect).

6.2 Validation Design

The external and internal validity, defined in the research methodology (Paragraph 2.2), provided information on the strategic sampling of data and the triangulation of sources. Due to the exploratory nature of this research, there is no strict methodology for validation of the data analysis (Verschuren & Doorewaard, 2013). This paragraph describes the validation focus group and validation questionnaire for the validation of the data analysis.

Validation focus group

Firstly, a session with a validation focus group was set up. A focus group is a multi-respondence interview (Verschuren & Doorewaard, 2013). Since actors with different perspectives were likely to have different and/or opposing stakes, it was chosen to validate by means of a focus groups with representatives from one actor. Representatives from the service supplier perspective were part of the focus group, since the service supplier generally has a central role in the project organisation of construction projects. The representatives of the service supplier were selected on the same criteria as the exploratory interviewees (Paragraph 3.2).

The representatives were sent a brief summary of the data analysis. During the session, the opinions of all representatives on the data analysis were discussed. These opinions were processed in the conclusions.

Validation questionnaire

Secondly, a validation questionnaire was conducted with respondents of actors from three different perspectives (i.e. FMCG manufacturer, service supplier and process product supplier). The respondents were selected on the same criteria as the exploratory interviewees (Paragraph 3.2), only with actors from three different perspectives instead of only from the service supplier perspective.

A brief summary of the data analysis and a questionnaire with closed and open questions was sent to the respondents. The questionnaire was characterised by a high degree of pre-structuring. Therefore, the answers of all respondent were comparable and conclusions can be drawn (Verschuren & Doorewaard, 2013).

Data Collection

(Picture Royal HaskoningDHV, case study project 2A in Russia)

Data Collection

The third part of this thesis, the data collection, presents all data collected by the three different methods of data collection. This part is divided into two chapters, according to the different themes of the sub research questions. The first chapter presents the data collected on the current situation (Chapter 7) and in the second chapter the data collected on the transition is presented (Chapter 8).

Research Context | Research Design | **Data Collection** | Data Analysis | Result

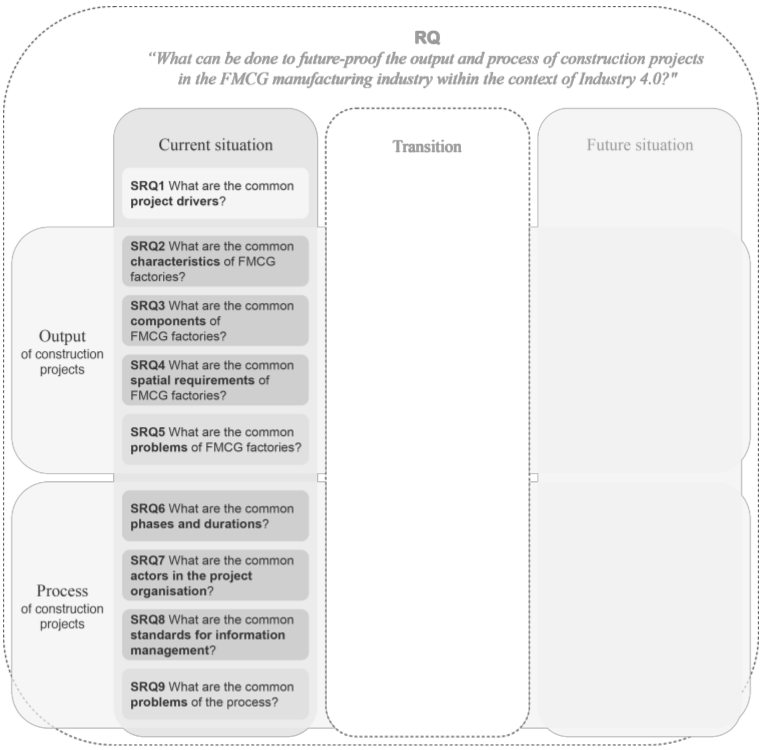
7

Current Situation

This chapter presents the data collected on the current situation of construction projects in the FMCG manufacturing industry. The data presented in this chapter was derived by all three methods of data collection. The chapter is divided into three paragraphs, according to the different themes of the sub research questions. The first paragraph describes the current project drivers (Paragraph 7.1). The second paragraph describes the current output (Paragraph 7.2) and in the third paragraph the current process is described (Paragraph 7.3).

All paragraphs are divided into sub paragraphs, according to the different themes of the sub research questions.

Moreover, in all paragraphs, firstly, the link to the research context is made, the data collected by exploratory interviews is presented, the data collected by the multiple-case-study is presented and the data collected by the literature review is presented.



7.1 Current Project Drivers

As mentioned in the research context on construction projects (Paragraph 1.1.3), traditionally, project drivers measuring project success in the construction industry are time, cost and quality, within in a fixed scope. Organisation and information are defined as project control aspects, instead of as project drivers. (Atkinson, 1999; Hesham Hyari, 2005). Since this approach has been criticized (Koolwijk & Vrijhoef, 2014) and construction projects in the FMCG manufacturing industry have different characteristics than other types of construction projects (e.g. the pressure of consumer demands in the FMCG market and the specialist character of FMCG manufacturing facilities compared to other built objects), this paragraph will focus on project drivers specifically for construction projects in the FMCG manufacturing industry.

At the beginning of construction projects in general, a project driver analysis (also called a business priority analysis) is done by the initiator of the project, to determine the project drivers for the project. However, other actors in the project organisation may have a focus on different project drivers (Exploratory interview, 14th of May 2018).

In the FMCG manufacturing industry, the initiator of the project, the FMCG manufacturer, is said to focus most on time (Exploratory interview, 14th of May 2018). Time and cost are strongly related project drivers, since a delay of construction project in general usually directly results into higher costs (Bascle et al., 2012). This relation is even stronger the FMCG manufacturing industry, since delays of construction projects not only result into higher costs of the project, but also into loss of revenue (i.e. loss of operational days of the factory) for the FMCG manufacturer.

With six out of eight exploratory interviewees, project drivers in construction projects in the FMCG manufacturing industry, were discussed. By asking the interviewees to choose the most important project driver(s) from the traditional project drivers, from the service supplier perspective, it was observed the service supplier generally focuses most on time and least on quality (Table 7-1).

Focus on traditional project drivers from service supplier perspective								
Exploratory interviewees [1]	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Time	•	•	•	•	n/a [2]	n/a	•	
Cost	•	•			n/a	n/a	•	•
Quality		•			n/a	n/a		
Fixed scope	•	•		•	n/a	n/a		

[1] *Exploratory interviewees numbered as 1-8*
[2] *N/a = non-applicable, which means the subject of project drivers was not part of the exploratory interview*

Table 7-1 - Current project drivers - Focus on traditional project drivers from service supplier perspective (Exploratory interviews)

By asking the interviewees to name other project drivers than the traditional ones, the following were named once for construction projects in general: information, safety and sustainability (Exploratory interview, 14th of May 2018). Changeability was named three times specifically for construction projects in the FMCG manufacturing industry (Exploratory interview, 27th of March 2018; Exploratory interview, 7th of May 2018; Exploratory interview, 8th of May 2018 - 2).

Moreover, the causes leading to the pressure on and prioritising of project drivers were discussed with the exploratory interviewees and case study interviewees. The causes related to the FMCG manufacturing industry specifically are described.

Primary or secondary process

Project drivers and the pressure on these drivers are said to be highly dependent on the so-called primary or secondary nature of the project. A project of primary nature is related to the primary process of the factory, the manufacturing of goods, and results into an increased manufacturing volume of the factory. A project of secondary nature is related to the secondary process of the factory, the support of the manufacturing, and does not result into an increased manufacturing volume of the factory, but for example into increased safety standards. For construction projects in the FMCG manufacturing industry, projects of primary nature are time-driven, because revenue can be generated with each day of FMCG bulk manufacturing. Whilst projects of secondary nature are cost-driven, because of the highly competitive FMCG market and the generally low margins of FMCG (Exploratory interview, 7th of May 2018).

Competitiveness FMCG market

In the FMCG manufacturing industry the level of competitiveness is high and throughout the value chain, speed is used as competitive weapon (Bascle et al., 2012). Which results into time-driven construction projects. Moreover, the FMCG manufacturing industry of multinational manufacturers is mature. Practical experience has shown, only two multinational manufacturers, producing the same kind of FMCG, can gain enough market share locally to open a factory (Case study interview, 4th of June 2018).

FMCG margin

Low margin of goods is usually related to bulk manufacturing and a highly competitive market (Bascle et al., 2012). The margins of goods produced in the factory influence the project drivers. Generally, projects of factories producing low margin goods have a bigger pressure on all project drivers. Moreover, these projects focus more on time and cost, instead of quality, because of the high level of competitiveness. In the FMCG manufacturing industry, goods produced mostly have low margins, and therefore, the projects focus on time and cost, instead of quality (Exploratory interview, 7th of May 2018).

Commitment of budget

Experience shows, generally, the change of the project drivers over the time of the project related to the commitment of the budget to the project. When the budget is not committed yet, projects are generally cost-driven. Projects become more time-driven when the budget is committed. For multinational FMCG manufacturers, this change in project drivers is even stronger, since the project organisation can be divided into global and local organisations with different stakes (Case study interview, 12th of June 2018).

The focus on project drivers of project initiated by three different FMCG manufacturer (i.e. 1, 2, 3) are compared, based on observations from the interviews with interviewees from the service supplier perspective (abbreviated as S) and the FMCG manufacturer perspective (abbreviated as M) (
Table 7-2).

Focus on traditional project drivers of specific FMCG manufacturers						
FMCG manufacturers [1]	*1*		*2*		*3*	
Perspective [2]	*S*	*M*	*S*	*M*	*S*	*M*
Time	•	•	•	•	•	
Cost	•		•		•	•
Quality	•					
Fixed scope	•		•		•	

[1] *FMCG manufacturers numbered as 1-3*
[2] *S = Service supplier perspective / M = FMCG manufacturer perspective*

Table 7-2 - Current project drivers - Focus on traditional project drivers of specific FMCG manufacturers (Case study interviews)

Moreover, the observations from the service supplier perspective and the FMCG manufacturer perspective on five different construction projects (i.e. 1A, 1B, 2A, 2B, 3) of the three different FMCG manufacturers (i.e. 1, 2, 3) are compared (Table 7-3).

Focus on traditional project drivers of individual case study projects										
FMCG manufacturers [1]	*1*				*2*				*3*	
Case study projects [2]	*1A*		*1B*		*2A*		*2B*		*3*	
Perspective [3]	*S*	*M*	*S*	*M*	*S*	*M*	*S*	*M*	*S*	*M*
Time	•	•	•	n/a [4]			•	n/a	•	
Cost	•			n/a	•	•		n/a	•	•
Quality		•	•	n/a				n/a		
Fixed scope	•			n/a			•	n/a		

[1] *FMCG manufacturers numbered as 1-3*
[2] *Case study projects numbered as 1A, 1B, 2A, 2B, 3*
[3] *S = Service supplier perspective / M = FMCG manufacturer perspective*
[4] *N/a = non-applicable, which means the subject of project drivers was not part of the case study interview*

Table 7-3 - Current project drivers - Focus on traditional project drivers of individual case study projects (Case study interviews)

From the comparison of the observations from the different perspectives, the different FMCG manufacturers and the different individual case study projects, the following statements can be made:

- The focus on the traditional project drivers is generally most on time.
- The focus from the service supplier perspective generally differs from the focus of the FMCG manufacturer perspective.
- The focus from the service supplier perspective is more on the fixed scope than from the FMCG manufacturer perspective.

7.2 Current Output

This paragraph describes the current output of construction projects in the FMCG manufacturing industry. The paragraph is divided into four sub paragraphs, according to the different themes of the sub research questions. The first paragraph describes the characteristics of the current output (Paragraph 7.2.1). The second paragraph describes the components of the current output (Paragraph 7.2.2). The third paragraph describes the spatial requirements of the current output (Paragraph 7.2.3) and in the fourth paragraph the problems of the current output are described (Paragraph 7.2.4).

7.2.1 Characteristics

In the research context (Paragraph 1.1.2), the characteristics of FMCG and the FMCG market from the perspectives of different actors in the value chain (i.e. FMCG manufacturer, FMCG retailer and consumer) are described (Table 1-1). The FMCG manufacturing industry and the FMCG factory itself are influenced by these specific characteristics. First, the influence of these characteristics on the output (i.e. FMCG factory) will shortly be described and secondly, different classifications based on the characteristics of FMCG factories will be made. The goal of this paragraph is to differentiate FMCG factories from other types of factories, to eventually relate find the specific characteristics of construction projects in the FMCG manufacturing industry.

Characteristics FMCG and FMCG market

In the research context (Paragraph 1.1.2), the characteristics of general manufacturing environments and FMCG manufacturing environments are described (Table 1-2). In this paragraph, the characteristics of FMCG and the FMCG market influencing the manufacturing environments are described.

Observations from exploratory interviews and the multiple case study show the unpredictability of the demand in the FMCG market. From the demand, the three dimensions of specification, volume and moment are found to be the most unpredictable (Case study interview, 14th of June 2018; Exploratory interview, 8th of May 2018 - 2). Similar observations are found in literature.

Van Donk (2001) defined specific market characteristics, their value in the FMCG market and their challenges related to manufacturing (Table 7-4). For example, the short delivery time causing low controllability in the manufacturing environment.

Market characteristics	Value in FMCG market	Manufacturing challenges
Delivery reliability	High	Long lead times and high initial costs
Delivery time	Short	Low controllability
Predictability of demand	Unpredictable	Costs of stock-holding
Specificity of demand	Great variety end goods	Risk of obsolescence

Table 7-4 - Characteristics - Market characteristics in the FMCG market related to manufacturing challenges (Van Donk, 2001)

Moreover, the manufacturing challenges defined (Van Donk, 2001) are strengthened by characteristics of the FMCG value chain, in which cooperation between actors takes place, but no close integration. Also, the FMCG market is characterised by fierce competition, which makes the pressure on delivering in the FMCG manufacturing industry even higher (Van Wezel et al., 2006).

The FMCG manufacturing challenges, caused by the specific characteristics of FMCG and the FMCG market, result into challenges for the output of construction projects in the FMCG manufacturing industry. The output, being a built object, is generally not able to react on the unpredictable demand. Moreover, since FMCG are bulk goods, the factories are generally not able to produce a great variety of end goods, rather a bulk of similar goods

Classification of FMCG factories

FMCG factories can be classified based on differentiation in specific characteristics. In the research context (Paragraph 1.1.2), four types of FMCG are distinguished, on which also the classification of FMCG factories can be made: household care, personal care, health care and food and beverages (Steenkamp & Geyskens, 2014). By comparing the case study projects, three classifications based on the good's substance are found: liquid, powder and solid.

For general manufacturing environments, five types manufacturing process can be distinguished: discrete, job shop, repetitive, batch and continuous. From discrete to continuous the manufacturing goes up and the variety of goods goes down (American Industrial Works, 2018). Therefore, the three classification of FMCG factories, based on their manufacturing process, can be made: repetitive (i.e. dedicated production lines producing same or similar goods), batch (i.e. dedicated production lines producing batches of same goods) or continuous (i.e. dedicated production lines producing some goods continuously).

The output construction projects in the FMCG manufacturing industry, i.e. FMCG factories, can classified following the three different classifications described. The most applicable classification will be defined in combination with the information on the components and spatial requirements.

7.2.2 Components

The characteristics of FMCG factories, established in the last paragraph (Paragraph 7.2.1), provided information on the differentiation of FMCG factories from types of factories. In this paragraph, the similarities between FMCG factories are researched by comparing the components of different FMCG factories.

Wiendahl et al. (2007) defined six spatial levels of manufacturing environments. Each level can be divided into components of the underlying level: network of plants, locations, masterplans (i.e. plants), buildings (e.g. factories, distribution centres, etc.), building blocks and units. This means the components of masterplans (i.e. plants) are buildings, for example factories, and the components of buildings are building blocks. The building blocks can be differentiated from each other, according to their different functions and different spatial requirements such as floor load, height, climate, energy provision, etc. (Wiendahl et al., 2007). The spatial requirements are further described in the next paragraph (Paragraph 7.2.3).

Components of masterplans

The components of the masterplans of manufacturing environments are based on the logistics of the masterplan. Next to the factory or factories, the masterplan consists of the following components: the entrance for raw materials, the exit for finished goods, the entrance and exit for trucks, the entrance and exit for staff, potential extra warehousing and a potential distribution centre (Exploratory interview, 2nd of May 2018 - 1). For FMCG plants specifically, these components are similar. However, differences between general plants and FMCG plants can be found:

- Less staff facilities on FMCG plants, since labour intensity is declining more rapidly (Processing & Packaging Machinery Association, 2016).
- Less extra warehousing, since FMCG are perishable (Constantinides, 2004).

Components of factories

The masterplans and factory plans of the different case study projects are compared to each other to find similarities. The case study projects can be classified differently, therefore, the similarities found are not related to a specific classification of FMCG factories. The similar building blocks found in the factory plans of the case study projects are:

- Raw materials warehouse
- Material process unit 1
- Unfinished good warehouse
- Material process unit 2
- Finished good warehouse
- Packaging unit
- Packaged good warehouse
- Utilities unit

The order of the building blocks is related to the flow of mass through the factory, only the utilities unit is not part of this flow. The processing, warehousing and packaging building blocks are clearly separated, because of different functional characteristics (Van Wezel et al., 2006). For the processing building blocks, consisting of production units, the components will be described.

Components of production units

The components of production units can be defined as machinery and equipment. Generally, four types of machinery for FMCG factories can be distinguished (Table 7-5). The packaging and bottling machinery are not often found in other types of factories than FMCG factories and are therefore clear differentiators from other factories and clear similarities between FMCG factories.

Types of machinery and equipment	
Processing machinery	*"Assets used in the manufacturing process to make, clean or pump the good"*
Packaging machinery	*"Assets used in the packaging process to convey and package the good"*
Bottling machinery	*"Assets used in the rinsing, filling, capping, labelling of the good"*
Plant equipment	*"Assets used in the supportive role of daily industrial plant activities"*

Table 7-5 - Components - Types of machinery and equipment (American Industrial Works, 2018)

For the output construction projects in the FMCG manufacturing industry, the similarities between the components of the masterplan, factories and production units of different plants and factories, indicate the similarities between the output of construction projects in the FMCG manufacturing industry.

7.2.3 Spatial Requirements

The components of FMCG factories, established in the last paragraph (Paragraph 7.2.2), provided information on the similarities between FMCG factories by comparing their components. In this paragraph, the spatial requirements of FMCG factories and different components are researched, to be able to further compare different FMCG factories.

Spatial requirements are capabilities of the physical space (Davis, 1993). Three types of spatial requirements can be distinguished: architectural, user and functional requirements (Brennan, 2009). The components of factories, the building blocks, can be separated based on their functional spatial requirements. These functional spatial requirements can be translated into architectural spatial requirements, such as surface (i.e. m^2), floor load, height, climate and light and the provision of energy and media (ICT) (Wiendahl et al., 2007).

For FMCG factories, which generally produce bulk goods for which the logistics in the factories is important, the logistic process determines the spatial requirements (Exploratory interview, 14th of May 2018). Factories producing bulk goods are assumed to have by a higher degree of standardisation of their spatial requirements, since the manufacturing process does not change, but continuously produces the same goods (Case study interview, 13th of June 2018; Case study interview, 14th of June 2018).

Moreover, observations from case study interviews show the FMCG manufacturer's and service supplier's need of standardisation of spatial requirements of FMCG factories. These can be found in appendix D.3 (Table D-8). However, the conflicting interests of different stakeholders in project organisations of FMCG manufacturers go against this need: global management of FMCG manufacturers desires fully standardised factories, whilst the operational companies (OpCo's) of factories desire specific requirements for individual factories (Case study interview, 12th of June 2018). Which could be one of the reasons why the spatial requirements of the case study projects are not standardised.

Already since the beginning of the 19th century, research has been trying to find standards for the spatial requirements and layout of manufacturing facilities. Aiming at decreasing the complexity of manufacturing facilities and therefore easing the process of designing and constructing these facilities (Drira, Pierreval, & Hajri-Gabouj, 2006; Gibb & Isack, 2001; Noyes, 1919). The overview of the main findings from the three researches can be found in appendix E.1.1 (Table E-1; Table E-2; Table E-3).

Noyes (1919) researched the phasing of defining certain factors that eventually define spatial requirements in the manufacturing industry (Appendix E.1.1, Table E-1). By standardising the process of defining the spatial requirements, by studying, planning and designing certain factors upfront, a more standardised set of spatial requirements can be made for the output of construction projects in the manufacturing industry.

Drira et al. (2006) defined several dimensions of the manufacturing facility layout (Appendix E.1.1, Table E-2). The type of manufacturing system, related to the product variety and the production volume, can result into four different types of layout: product layout, cellular layout, process layout and fixed product layout (Figure 7-1).

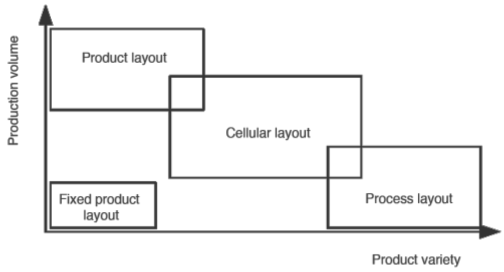


Figure 7-1 - Spatial requirements - Manufacturing layout based on manufacturing system (Drira et al., 2006)

Since FMCG factories have a high production volume and a great product variety, there is not one of these four layouts directly applicable, but combination between the product and process layout would be possible. Product layouts are organised according to the production flow and process layouts are organised by grouping facilities with similar functions together (Drira et al., 2006).

Another dimension of the manufacturing facility layout are the constraints, e.g. area constraints (Drira et al., 2006). From the multiple-case study is observed, brownfield projects (i.e. renovations, expansions, improvements, etc.) are often constrained by the current project site, due for example the availability of space. Moreover, the redevelopment of existing sites often happens while there still is a process running, which leads to more spatial constraints of the construction project (Case study interview, 4th of July 2018). Moreover, an extra challenge in brownfield projects is figuring out the details of what is already there, for example the current conditions and the current performance (Merrow, 2011).

Moreover, Drira et al. (2006) state several objectives regarding the manufacturing facility layout: minimal space, handling and rearrangement costs, minimal shape irregularities and minimal backtracking and bypassing. Shape irregularities means the facility shapes are not regular squares or rectangles. Backtracking and bypassing are related to the production flow not directly following the logical sequence of the building blocks (Figure 7-2).

Facility shapes (left regular, right irregular) Backtracking and bypassing

Figure 7-2- Spatial requirements - Layout objectives related to facility shapes and backtracking and bypassing (Drira et al., 2006)

Gibb and Isack (2001) defined standardised products and components related to standardised processes and procedures for the standardisation of construction projects (Appendix E.1.1, Table E-3). For example, standard buildings can be realised by the use of standard processes, procedures and techniques. Or similar building solutions can be applied on different locations when there is centralised purchasing and specification.

The global organisations of FMCG could take the lead in standardising the processes and procedures in construction projects to assure a more standardised output. Moreover, service suppliers, engineering and designing factories for different FMCG manufacturers could take the lead in standardisation across FMCG manufacturers (Case study interview, 4th of June 2018).

7.2.4 Problems Current Output

The overarching problem of the output of construction projects in the FMCG manufacturing industry, from FMCG manufacturer perspective, is defined as not being able to manufacturer the demand of the FMCG retailer and/or FMCG. As defined in the research context (Paragraph 1.1.2) a demand for consumer goods consists of a specification (e.g. good type, etc.), volume (e.g. packaging size, etc.), moment and location (Constantinides, 2004).

For this research, a root cause analysis on data from the exploratory interviews, the multiple case study and the literature review was done to identify the root causes (i.e. initial causes) of the overarching problem. The following root causes for the problem of not being able to manufacturer the demand are found:

- Limited changeability and integration
- Opposing market requirements and manufacturing wishes
- Manufacturing complexity

- **Limited changeability and integration**

Five out of eight exploratory interviewees stated the problem of not being able to meet the demand could be caused by limited changeability of and/or limited integration in FMCG factories (Table 7-6). A literature review on the concepts of changeability and integration was done to gain better understanding of these concepts and their implications for the output of construction projects in the FMCG manufacturing industry.

Limited changeability and limited integration as root cause for problem of overarching problem FMCG factories								
Exploratory interviewees	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Limited changeability	•			•	•		•	•
Limited integration	•	•	•		•	•		

Table 7-6 - Problems current output - Limited changeability and limited integration as root cause for overarching problem FMCG factories (Exploratory interviews)

- **Changeability**

Das and Patel (2002, p. 266) defined changeability as *"the ability of a system or facility to adjust to changes in its internal or external environment".* Moreover, this means changeability is the ability of a system or facility to cope with uncertainty (Brettel et al., 2016).

Changeability is related to change, and change can be defined as *"the transition of a system over time"* (Ross, Rhodes, & Hastings, 2008, p. 2). The change event consists of three aspects: the force causing the change, the path of the change and the effect of the change. The force causing the change can be internal or external (Ross et al., 2008). Therefore, the changeability of a system can also be divided into two abilities (Wiendahl et al., 2007):

- Adaptability: the ability of a system to adjust to internal forces causing change
- Flexibility: the ability of a system to adjust to external forces causing change

Examples of internal changes, adaptability-type changes, in the FMCG manufacturing industry are changes in internal processes, internal policies, for example due to internal failures (Brettel et al., 2016; Das & Patel, 2002). Partly retrieved from exploratory interviews (Table 7-7), examples of external changes, flexibility-type changes, in the FMCG manufacturing industry are changes in one of the different dimensions of demand: specification, volume, moment and location. These dimensions can be divided into more specific categories. For example, volume can be divided into general and packaging.

Flexibility-type changes								
Exploratory interviewees	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Specification - Goods portfolio	•			•			•	•
Volume - General	•			•	•		•	•
Volume - Packaging	•						•	•

Table 7-7 - Problems current output - Flexibility-type changes (Exploratory interviews)

The demand dimension of specification can be divided into the following specification levels: goods portfolio (i.e. set of goods), good, sub good, workpiece and feature (Wiendahl et al., 2007). The speciation levels can be related to the components of factories (Paragraph 7.2.2) to define the different gradations of changeability (Table 7-8).

Changeability gradations related to different components of manufacturing environments and specification levels					
Goods portfolio					Agility
Good				Transformability	
Sub good			*Changeability*		
Workpiece		Reconfigurability			
Feature	Change-over				
Specification levels	Unit	Building block	Building (e.g. factory)	Masterplan (i.e. plant)	Network of plants
	Components of manufacturing environments				

Table 7-8 - Problems current output - Changeability gradations related to different components of manufacturing environments and specification levels (Wiendahl et al., 2007)

All the abilities to change should be with minimal effort and minimal delay. When the changeability of a factory is conceived as a problem, it is recommended to improve all the gradations of changeability:

- Change-over ability is a single machine, performing another task to change a good's feature
- Reconfigurability is an assembly system switching between workpieces of a good
- Changeability is changing the entire manufacturing and logistic system by changing manufacturing processes, material flows and logistical functions
- Transformability is restructuring the entire plant to switch change between goods
- Agility is opening up new markets, by develop new goods

For this research, focusing on the FMCG factories as output of construction projects in the FMCG manufacturing industry, different types of changeability are found (Table 7-9) (Browne, Dubois, Rathmill, Sethi, & Stecke, 1984; Das & Patel, 2002; Gupta & Somers, 1992).

Changeability types	Definitions (Browne et al., 1984, pp. 114–115)
Routing	*"Ability to process a given set of part types via alternative routes"*
Process	*"Ability to produce a given set of part types via alternative processes"*
Operation	*"Ability to interchange the ordering of operations"*
Volume	*"Ability to operate profitably at different volumes"*

Table 7-9 - Problems current output - Different types of process flexibility and their relations (Browne et al., 1984; Das & Patel, 2002; Gupta & Somers, 1992)

By focusing on increasing routing, process, operation and volume changeability, FMCG factories could increase their changeability. This could be the start of increasing the overall changeability of manufacturing environments (Wiendahl et al., 2007).

- **Integration**

System integration can be described as bringing together sub-systems into one functioning system, for example by the exchange of information, functionalities and the interdependencies between sub-systems. Factors to assess the different strengths of integrations are (Eriksson, 2015):

- Strength of integration: number of interdependencies between activities of sub-systems
- Scope of integration: internally linked processes sub-systems, linked to external environment
- Depth of integration: number of sub-systems involved in integrative activities
- Duration of integration

For FMCG factories, the interdependencies between the activities of sub-systems is related to the flow of goods through the factory. The goods produced internally are linked to the demand of goods externally. The number of sub-systems involved in the manufacturing is dependent on the type of FMCG.

Moreover, Zhou et. al. (2016) and Wang, et. al. (2016) have defined three different types of integration for the manufacturing industry specifically:

- Horizontal integration: integration of different actors within the value chain
- Vertical integration: integration of different disciplines within an actor
- End-to-end integration: integration of processes within the value chain

For FMCG factories, horizontal integration means the integration of raw materials supplier, FMCG manufacturer, FMCG retailer and consumer. Vertical integration means the integration of the civil (i.e. building, facilities, logistics, etc.) and the process (i.e. machinery and equipment) disciplines. End-to-end integration is related to the construction projects of the FMCG factories and means the integration of all phases (i.e. initiation, design, construction and exploitation and maintenance) of construction projects of FMCG factories.

- **Limited changeability of and limited integration in FMCG factories**

With the understanding of the concepts of changeability and integration, the link to the problems of limited changeability and limited integration and the output of construction projects in the FMCG manufacturing industry (i.e. FMCG factories) can be made.

The need for changeability of FMCG factories can be substantiated by multiple findings from literature. The benefits of changeability are linked to the FMCG manufacturing industry specifically by Das and Patel (2002). Moreover, actors operating in the value chain of the FMCG industry state the need for changeability of FMCG factories, which is increasing (Duivenvoorden, 2017; Fry et al., 2017). However, based on practical experience from the service supplier perspective, limited changeability is still conceived as a problem for FMCG factories (Exploratory interview, 27th of March 2018; Exploratory interview, 2nd of May 2018 - 1; Exploratory interview, 7th of May 2018; Exploratory interview, 8th of May 2018 - 2; Exploratory interview, 8th of May 2018 - 1).

The need for integration is becoming more important by the increasing need for changeability (Wiendahl et al., 2007). Horizontal and end-to-end integration can be related to flexibility (i.e. for changes caused by external factors), by linking the demand of the FMCG value chain to the FMCG factory. Moreover, vertical integration can be related to adaptability (i.e. for changes caused by internal factors) of a FMCG factory, by linking the disciplines within the FMCG factory to each other.

However, findings from exploratory interviews show two causes for limited vertical integration in FMCG factories, due to little discipline integration generally and more specifically little process-civil integration (Table 7-10). The different disciplines in manufacturing environments are for example civil, process, architectural, mechanical, electrical and plumbing. In manufacturing environments generally, the disciplines of civil and process are the most important (Duivenvoorden, 2016).

Causes limited vertical integration								
Exploratory interviewees	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Little discipline integration		•					•	•
Little process-civil integration	•	•			•		•	

Table 7-10 - Problems current output - Causes limited vertical integration (Exploratory interviews)

Moreover, findings from the multiple-case study show limited integration in the FMCG factories. In two brownfield case study projects limited vertical integration in the parts that are already existed is observed (Case study interview, 6th of June 2018; Case study interview, 15th of June 2018 - 1). This results for example into backtracking and bypassing (Figure 7-2), because the goods flow is not integrated into the building blocks. For a greenfield case study project, the service supplier interviewed was contracted as integrator of the different disciplines. However, realising vertical integration during the design and engineering was observed to be very complex. Among other reasons, because of the many different product suppliers involved in the project (Case study interview, 27th of June 2018). Moreover, in the interview with the product supplier, the complexity of realising vertical integration with many different process product suppliers involved was confirmed (Case study interview, 4th of July 2018).

- **Opposing market requirements and manufacturing wishes**

The FMCG market characteristics causing manufacturing challenges were defined (Paragraph 7.2.1, Table 7-4). Moreover, a problem of opposing market demands and manufacturing wishes in the FMCG market is found (Table 7-11) (Van Wezel et al., 2006).

Opposing market demands and manufacturing wishes in the FMCG market		
Market demands	Manufacturing wishes	Description of oppositions
Manufacture to order	Continuous manufacturing	• As little time losses as possible due to change-overs, set-up, cleaning, stopping, etc. • Tight schedules with little slack • High capacity usage
Small orders	Bulk manufacturing	
Short lead times orders	Fixed sequence	

Table 7-11 - Problems current output - Opposing market demands and manufacturing wishes in the FMCG market (Van Wezel et al., 2006)

The FMCG manufacturing processes can be characterised as continuous, producing bulk goods, by using a fixed sequence. Moreover, it is tried to achieve the highest capacity usage as possible. However, the market demands of manufacturing to order, small orders and short lead times of orders interfere with these wishes, since change-overs between production lines are needed for these demands. Change-orders result into time losses (Van Wezel et al., 2006).

- **Manufacturing complexity**

Manufacturing complexity is defined as another cause for not being able to manufacturer the demand, for which four drivers have been defined: goods complexity, process complexity, organisational complexity, and market complexity (Elmaraghy, Elmaraghy, Tomiyama, & Monostori, 2012). In the FMCG manufacturing industry the goods complexity is high, since there is a great variety in goods (Van Donk, 2001). Also, the process complexity in the FMCG manufacturing industry is high, because specialised machinery and equipment for the processes are needed (Rhodes, 2014). Moreover, the organisational and market complexity of the FMCG market have been defined by the market characteristics and the related manufacturing challenges (Table 7-4) and the opposing market requirements and manufacturing wishes (Table 7-11). For the FMCG manufacturing industry specifically, the dynamic demand, goods variety and supply chain are translated into manufacturing complexity, since the physical domain of components (Paragraph 7.2.2) and spatial requirements (Paragraph 7.2.3) are not necessarily changeable (Elmaraghy et al., 2012).

7.3 Current Process

This paragraph describes the current process of construction projects in the FMCG manufacturing industry. The paragraph is divided into four sub paragraphs, according to the different themes of the sub research questions. The first paragraph describes the phases and durations of the current process (Paragraph 7.3.1). The second paragraph describes the project organisation in the current process (Paragraph 7.3.2). The third paragraph describes the information management in the current process (Paragraph 7.3.3) and in the fourth paragraph the problems of the current process are described (Paragraph 7.3.4).

7.3.1 Phases and Durations

In appendix D.4.1 (Table D-9; Table D-10; Table D-11), the data on phases and durations retrieved from the multiple-case study can be found. In appendix E.2.1 (Table E-4; Table E-5), the data on phases and durations from the literature review can be found.

In the research context (Paragraph 1.1.3), the four phases for general construction projects are defined as: initiation, design, construction and the last phase, consisting of exploitation and maintenance. In the mid-20th century, Mayer (1960) researched the duration of construction projects in the manufacturing industry and assigned 7 months to the design phase and 15 months to the construction phase (Appendix E.2.1; Table E-4). From the multiple-case study the following average durations for the four phases are found (Appendix D.4.1; Table D-9; Table D-10; Table D-11):

- Initiation phase: minimally 6 months
- Design phase: around 6 months
- Construction phase: 12-15 months
- Exploitation and maintenance phase: 1 year

The decision-making steps and deliverable of each phase are described.

Initiation phase and design phase (i.e. front-end phases)

Merrow (2011) defined sub phases of the initiation and design phases and defined the general deliverables for these phases, for construction projects in the manufacturing industry (Appendix E.2.1; Table E-5). The first sub phase of the initiation phase is specifically related to the manufacturing industry. The phase in which the business idea and the business case are defined, does not necessarily occur in general construction projects.

For construction projects in the FMCG manufacturing industry, the FMCG manufacturer continuously focusses on defining business opportunities by continuously making business cases (Exploratory interview, 8th of May 2018 - 2). Business cases generally consist of a market analysis, a competition analysis, a Capex and Opex analysis and a business plan (Merrow, 2011). Capex, capital expenditure, represents all investments in goods or services that will be used for more than one year. Opex, operational expenditure, represents all costs for a company to run its daily operations (Exploratory interview, 8th of May 2018 - 2). Business cases in the FMCG manufacturing industry are continuously changing, because the business opportunities continuously change due to changes in the external environment, for example changing market demand, changing competition, etc. (Fry et al., 2017).

When a business case is approved by the global management of the FMCG manufacturer, the budget for the construction project is committed and a so-called project proposal is made (Case study interview, 19th of July 2018). The duration of the design phase, from the commitment of the budget and schedule to the start of construction, is generally 6 months. Since the budget is already committed to the project in the design phase, the duration of the design phases of different projects is more similar than the initiation phases of different projects.

Focus on the front-end phases, by investing in front-end project management and project planning, generally positively influences the traditional project drivers of construction projects: time, cost and quality, within a fixed scope (Exploratory interview, 8th of May 2018 - 2). More specifically related to the fixed scope, advantages of front-end focus can be (Sarde et al., 2016):

- Fewer scope changes in later phases of the project
- Fewer design changes in later phases of the project

Moreover, better management of uncertainties during the project can be an advantage of front-end focus. However, there will always be the so-called "unknown unknowns": uncertainties that are not known upfront and on which cannot be anticipated (Leijten, 2016). For these uncertainties a changeable process is needed rather than investing more management and planning upfront to try to anticipate on them. For construction projects in the FMCG manufacturing industry specifically, a changeable process is of higher importance than general construction projects, since the FMCG market can be characterised as a volatile market (Fry et al., 2017).

Construction phase and exploitation and maintenance phase

Based on data on the duration of phases of the case study projects (Appendix D.4.1; Table D-9; Table D-10; Table D-11), it is observed the duration of the construction phase in construction projects in the FMCG manufacturing industry, is one year minimally. The construction phase ends with the commissioning of the factory, which means the whole of the factory is tested to be prepared for the first production day. After the first production day, the operational factory is still monitored for one year by the project organisation of the construction project. After one year, the final hand-over of the factory from the project organisation to the operational factory of the company takes place (Case study interview, 18th of June).

7.3.2 Project Organisation

Related to the problem definition (Paragraph 2.1.1), the internal and external actors and the stakeholders of construction projects in the FMCG manufacturing industry specifically (Figure 2-1) are identified. In general, construction projects are characterised by the involvement of many actors and stakeholders (Lester, 2007). Vrijhoef and De Ridder (2005) make a division between the so-called demand and supply system of a building. The demand system consists of actors and stakeholders with a specific demand related to the building. The supply system consists of actors that supply the building with services or products.

In the FMCG manufacturing industry, the demand system of the factory can be seen as the actors in the FMCG value chain (Figure 1-3) demanding goods from the factory: the FMCG retailer and the consumer. Moreover, within organisation of the factory itself, actors in the demand system can be found. For example, the global department of the FMCG manufacturer demanding revenue and the operational company of the FMCG factory demanding work. On the opposite, in the supply system the service suppliers, the product suppliers and the project organisation of the FMCG factory can be found.

FMCG manufacturers

As described above, FMCG manufacturers can be seen as demanders and suppliers of the FMCG factory (Vrijhoef & de Ridder, 2005). Therefore, the organisation of FMCG manufacturers can be divided into different actors, with different and sometimes opposing stakes related to the construction projects. For example, global management wants the project to maximise the revenue, whilst the operational company wants a workable factory (Case study interview, 27th of June 2018).

The FMCG manufacturers, from which projects were researched as multiple-case study, have similar divisions. Since all FMCG manufacturers researched are multinational manufacturers, all three FMCG manufacturers have a division into global and local organisations.

The international character of construction projects in the FMCG manufacturing industry makes the project organisation decentralised without physical proximity to the project / construction site (Dallasega et al., 2018).

Another similarity of the organisations of the different FMCG manufacturers, is the “islands” of specialists. Construction projects in the FMCG manufacturing industry need a very specific kind of knowledge, based on experiences in this industry, such as a specific technical background or a process background. However, these specialists are observed to work on their own islands, instead of working closely together (Case study interview, 15th of June 2018 - 2).

The initiating party of the project, the FMCG manufacturer, often operates in framework contracts and therefore stimulates long term collaboration with both service and product suppliers. Generally, long-term collaborations smoothen the process. However, partnerships (i.e. long-term collaborations) between the FMCG manufacturer and suppliers are not always formed. Partnerships may cause the loss of sharpness between actors and the loss of eagerness to achieve a good result, to impress the other actor (Case study interview, 27th of June 2018).

Service suppliers and product suppliers

In appendix D.3, data on the case study projects can be found, including the billed work breakdown for the FMCG manufacturer of the service supplier (Table D-5; Table D-6). The work breakdown presents the work of the service supplier on the project in different so-called work packages.

By comparing the budget breakdowns of the case study projects, a general budget breakdown can be made. Generally, for construction projects in the FMCG manufacturing industry, a share of 10 % from the total budget is committed to the service suppliers, supplying services such as design, engineering and consultancy. A share other 90 % of the budget is committed to the product suppliers. From the budget committed to the product suppliers, generally, 30 - 40 % is committed to civil product suppliers and 60 - 70 % is committed to process product suppliers (Table 7-12) (Exploratory interview, 8th of May 2018 - 2). Civil product suppliers deliver products related to the facility, such as foundation, floors, walls, etc. Whereas the process product suppliers deliver products related to the manufacturing process, such as machinery and equipment.

Breakdown of total budget construction projects in the FMCG manufacturing industry			
Budget	100 % - Total project budget		
Breakdown 1	90 % - Product suppliers		10 % [1]
Breakdown 2	30 - 40 % Civil product suppliers	60 - 70 % Process product suppliers	

[1] *Service suppliers*

Table 7-12 - Project organisation - Breakdown of total project budget in the FMCG manufacturing industry (Exploratory interview, 8th of May 2018 - 2)

The general budget breakdown of the total project budget in the FMCG manufacturing industry takes greenfield projects (i.e. new projects) into account. However, for brownfield projects (e.g. renovations, expansions, improvements), the budget breakdown can be totally different. The budget breakdown is related to the work packages and therefore also related to the primary or secondary nature of the project. The difference of the budget breakdown of projects with a primary or secondary nature can be described by the different project drivers: time-driven and cost-driven, respectively (Paragraph 7.1).

The general breakdown of the total project budget for greenfield projects in the FMCG manufacturing industry shows the importance of the process product suppliers in the project organisation. However, from the interview with the process product supplier it is observed the importance of the process product suppliers is not always recognised by the FMCG manufacturer and the service supplier (Case study interview, 4th of July 2018).

7.3.3 Information Management

Strategic information management can be seen as knowledge sharing strategies (Leijten, 2016). A sender produces information and a receiver interprets information. The general complexity and organisational complexity (i.e. inter-disciplinarily) of large-scale construction projects ask for strategic information management and knowledge sharing strategies (Bektas et al., 2013). Knowledge sharing is the sharing of explicit (i.e. rational, factual and objective) and implicit (i.e. expertise, practice, beliefs and values) knowledge through communication and documentation. Technological aspects can be seen as tools related to knowledge sharing, social aspects can be seen as drivers and cultural aspects can be seen as drivers or constraints (Figure 7-3). Cultural similarities can be drivers for knowledge sharing, whereas cultural differences can be constraints for knowledge sharing (Bektas et al., 2013).

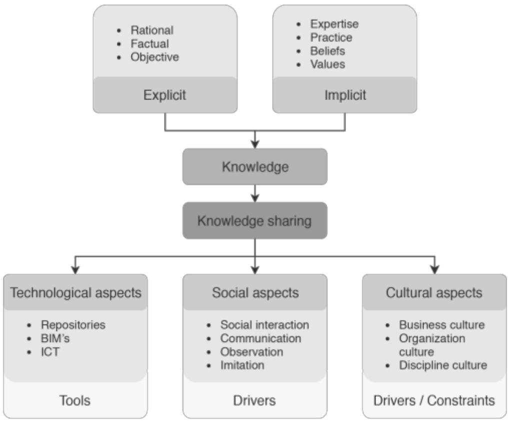


Figure 7-3 - Information management - Knowledge sharing framework (Own figure, based on Bektas et al., 2013)

Although this clear knowledge sharing framework exists, findings from the multiple-case study show poor knowledge sharing often occurs. Poor knowledge sharing can be caused by the risk of poor production of knowledge (e.g. wrong choice of information provider, complexity of the information, strategic interests) or/and the risk of poor interpretation of knowledge (e.g. limited comprehension, preoccupation of ideologies) (Leijten, 2016). In construction projects in the FMCG manufacturing industry, the production of knowledge is often poor, due to the complexity of the information. The complexity of the information is caused by the complexity of the manufacturing processes and the complexity of project organisations in construction projects in the FMCG manufacturing industry.

Related to the complexity of the information and organisation in the FMCG manufacturing industry, Dallasega et al. (2018) identified four types of proximity to the construction project: geographical, cognitive, technological and organisational proximity. The different types of proximity are measured by different key dimensions: distance, knowledge, compatibility and control, respectively.

Generally, construction projects are characterised by actors with little geographical and cognitive proximity to the construction project (Dallasega et al., 2018). This means the physical distance between the actor and the construction site is long (i.e. little geographical proximity) and the actor does not have all the knowledge related to the project (i.e. little cognitive proximity).

Both the geographical proximity and cognitive proximity are often even less for construction projects in the FMCG manufacturing industry. The geographical proximity of all actors is less, mainly in projects of multinational FMCG manufacturers, because of the international character of the construction projects. The cognitive proximity of all actors is often less, because of the many actors involved and the complex project organisation. However, the little geographical and cognitive proximity can be bridged by assuring technological (measured by compatibility) and organisational (measured by control) proximity to the decision-making unit. Findings from the multiple-case study show the technological proximity and the tools currently used for information sharing could still be improved.

7.3.4 Problems Current Process

The overarching problem of the process of construction projects in the FMCG manufacturing industry is defined as a poor project process in the perspective of one or more actors in in the project organisation.

For this research, a root cause analysis on data from the exploratory interviews and case study interviews was done to identify the root causes (i.e. initial causes) of the overarching problem. The following root causes for the problem a poor project process are found:

- Time overrun, cost overrun and limited quality
- Project organisation problems and challenges
- Information management problems and challenges
- Limited changeability of process of construction projects in FMCG manufacturing industry
- Limited integration in process of construction projects in FMCG manufacturing industry

The full root cause analysis can be found in appendix D.4.3 (Figure D-1 - Figure D-8). All root causes named in this text were present in at least three out of five case study projects.

- **Time overrun, cost overrun and limited quality** (Appendix D.4.3; Figure D-2 - Figure D-4)

From the observations of exploratory interviews, time overrun, cost overrun and limited quality are identified as causes for the overarching problem of a poor project process. All of these are root caused by a poor project definition, no project kick-off, late service and product supplies and little alignment of the process and civil disciplines (Table 7-13).

Time overrun, cost overrun, limited quality from exploratory interviews								
Exploratory interviewees	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Poor project definition	•				•			
No project kick-off			•			•	•	
Late supplies	•	•			•			
Little alignment process and civil	•		•	•				

Table 7-13 - Problems current process - Time overrun, cost overrun and limited quality (Exploratory interviews)

From the observations of the multiple-case study (Appendix D.4.3; Figure D-2 - Figure D-4), it becomes clear generally the FMCG manufacturer does the project definition, by defining the business idea and business case. This includes the definition of the planning and budget. However, the planning and budget can be unrealistic (planning too short and budget too low), due to the little knowledge of the FMCG manufacturer on these aspects. The late supplies are found to be root caused by late tendering, which can also be related to the unrealistic planning.

Moreover, findings from the multiple case study, showed the relation between organisational problems and time and cost overrun. Organisational problems can be related to the little alignment of the process and civil disciplines. The process discipline takes care of everything related to manufacturing in the factory. The civil discipline takes care of all civil works, such as the site logistics, the building and the utilities. If the planning these two disciplines are not aligned, problems can occur, due to the interdependencies between the disciplines.

- **Project organisation problems** (Appendix D.4.3; Figure D-5)

During the initiation phase, project organisation problems were caused by a lack of industry specific know-how of the service supplier. The service suppliers that do consultancy work and design and engineering support in the FMCG manufacturing industry, were observed not to have the industry specific knowledge needed.

Generally, construction projects are characterised by a lack of collaboration between actors (Hook, Geissbauer, Vesdo, & Schrauf, 2016). For construction projects in the FMCG manufacturing industry, little actor alignment and stakeholder engagement causes project organisation problems (Table 7-14).

During the design phases, project organisation problems can be caused by the poor collaboration with local actors (Table 7-14). During the construction phase, more specific root causes to the problem are found: problems with the operational companies of the factories (in case of brownfield projects) and problems with the local contractors and local suppliers.

Project organisation problems and challenges								
Exploratory interviewees	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Lack of know-how						•	•	•
Little actor alignment	•				•	•		
Little stakeholder engagement			•	•		•		
Collaboration local actors	•				•	•	•	

Table 7-14 - Problems current process - Project organisation problems and challenges (Exploratory interviews)

From the service supplier perspective, organisational problems during the processes of the case study projects are caused by time and cost pressure, complexity of the project organisation, different stakes in the organisation and local circumstances (Appendix D.3, Figure D-5). The problems related to the complexity of the project organisation and the different stakes in the organisation are root caused by the big number of companies, actors and stakes in the project organisation. The problems related to the local circumstances are root caused by the cultural differences between parties and the little professionality and experience of the local parties.

- **Information management problems** (Appendix D.4.3; Figure D-6)

Construction projects in general are characterised by problems related to information management, caused by the different "languages" of the different disciplines involved in projects (Ravesloot, 2007). For construction projects in the FMCG manufacturing industry, this cause is also observed (Exploratory interview, 2nd of May 2018 - 2).

Moreover, during the initiation phase, observations of the exploratory interviews show, the little time spent on project kick-offs as cause for information management problems. During the design phase, the contracts to product suppliers are awarded as late as possible, which causes problems for the level of detail of the information needed at certain points in the design planning (Exploratory interview, 8th of May 2018 - 1). Also, information management problems were often caused by not smoothly hand-overs from design to procurement (Exploratory interview, 23rd of March 2018).

For the case study projects, information management problems were caused by little to no standards, technological problems and the complexity of the project organisation (Appendix D.4.3, Figure D-6). The complexity of the project organisation causes poor information flows between actors and low transparency in the information exchange in construction projects in the FMCG manufacturing industry.

- **Limited changeability of process of construction projects in FMCG manufacturing industry** (Appendix D.4.3; Figure D-7)

Generally, construction projects are characterised by a lot of changes (Hook et al., 2016). The FMCG market is characterised as volatile (Fry et al., 2017), for which construction project in the FMCG manufacturing industry can also be characterised by a lot of changes. However, the processes of construction projects in the FMCG manufacturing industry are observed to have a limited changeability. Causes for limited changeability were stated in the exploratory interviews (Table 7-15). In the initiation phase, the choice for the location of the project and the design of the masterplan cause limited changeability, due to space constraints of the location and design constraints. Also, the over-specification of the design during the initiation phase limits the changeability of the project. If all aspects of the project are already defined in the initiation phase, the project is not changeable when internal or external changes occur. In the design phase, a constant trade-off between engineering and business choices is made. Limited changeability is caused by choosing business over engineering, since engineering for changeability generally costs more.

Limited changeability								
Exploratory interviewees	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Location choice and masterplan design	•					•		•
Over-specification				•	•			•
Business choices							•	•

Table 7-15 - Problems current process - Limited integration (Exploratory interviews)

Limited changeability during the process of the case study projects was caused by time and cost pressure, limited integration and fixed organisational structures (Appendix D.4.3, Figure D-7). The need for changeability is high, due to the continuous feedback loop to the business case, in which the manufacturing demand is established. Two out of three case study projects were put on hold after the design phase, right before the start of the construction phase. For one project, the civil products were already procured and on site before the project was put on hold. On the other hand, one case study project was planned to happen in three phases, to avoid over dimension and spread the risk of the investment. Already at the start of the construction of the first phase, the initiation and design of the second phase started. This also happened for the third phase after phase two. Both due to the feedback loop to the business case.

For construction projects in the FMCG manufacturing industry, the continuous feedback loop to the business case combined with the limited changeability of the process, can result into projects that are put on hold during the process (when demand decreases). Or, on the other hand, projects that already need extensions when they are not even finished yet (when demand increases).

- **Limited integration in process of construction projects in FMCG manufacturing industry** (Appendix D.4.3; Figure D-8)

From the exploratory interview, the following causes for limited integration in the process of construction projects in the FMCG manufacturing industry have been defined: limited information sharing between disciplines, the different phases in which disciplines are working, the hand-overs between disciplines and the general discipline alignment (Table 7-16). The main disciplines in construction projects in the FMCG manufacturing industry are the process and the civil disciplines. The interdependencies between the disciplines cause the need for information sharing, phasing alignment and structured hand-overs.

Limited integration								
Exploratory interviewees	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Information sharing	•		•		•	•		•
Phasing disciplines		•		•				
Hand-overs disciplines			•			•		
Discipline alignment	•	•			•		•	

Table 7-16 - Problems current process - Limited integration (Exploratory interviews)

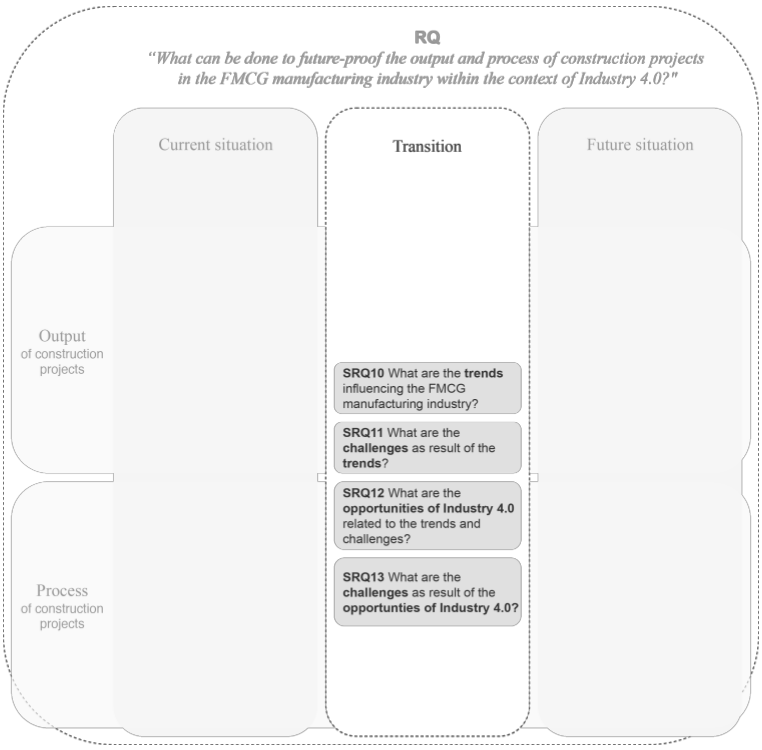
Observations from the multiple-case study show the need for integration and the complexity of the organisation as causes for the limited integration (Appendix D.4.3, Figure D-8). The complexity of the organisation is caused by the different companies covering the different disciplines and the different work approaches related to this.

In appendix F (Table F-1; Figure F-1; Figure F-2; Figure F-3), the synthesis of all data collected on the process in the current situation can be found.

8

Transition

This chapter presents the data collected on the transition of construction projects in the FMCG manufacturing industry. The data presented in this chapter was derived by the literature review. The chapter is divided into four paragraphs, according to the different themes of the sub research questions. The first paragraph describes the trends influencing the FMCG manufacturing industry (Paragraph 8.1). The second paragraph describes the challenges as a result of these trends (Paragraph 8.2). The third paragraph describes the opportunities of the Industry 4.0 transition related to these trends and challenges (Paragraph 8.3). The fourth paragraph describes the challenges of the transition as a result of the opportunities of the Industry 4.0
transition (Paragraph 8.4).



8.1 Trends

This paragraph introduces the trends influencing the FMCG manufacturing industry. A PESTE analysis is done. This analysis identifies and defines external and macroenvironmental trends, i.e. change factors, in five different categories: political, economic, social, technological and environmental (Ho, 2014). This analysis is used in practice and research to understand the change factors affecting the external environment of the business or research field (Rastogi & Trivedi, 2016). The PESTE analysis is chosen as a method, because the method helps to understand the research environment better, helps to anticipate on future uncertainties and challenges, and enables to spot new opportunities and exploit them effectively. Moreover, the five specific categories are chosen to assure an all-embracing and relevant identification of trends, i.e. change drivers (Rastogi & Trivedi, 2016).

Trends can be described as the general direction in which something is developing or changing (Dugarova & Gülasan, 2017). Since mega trends are characterised as being global, forcing development and being transformational (Dobbs et al., 2016), these three criteria were set for the identification and definition of the trends. Based on a systematic literature review of literature from the global organisations, the United Nations and the World Bank, the relevant trends are listed and relevant qualitative and quantitative data on the trends is collected. The relevancy of the trends and data is defined as affecting the FMCG manufacturing industry, by affecting the consumer demands and/or the manufacturing demands. Some trends are not directly affecting these demands but are relevant to mention to understand the other trends.

The goal of conducting a PESTE analysis is to identify and define the relevant trends affecting consumer demands (Paragraph 8.2.1), manufacturing demands (Paragraph 8.2.2) and therefore affecting the FMCG manufacturing industry (Paragraph 8.2.2) (Figure 8-1). These trends therefore also affect construction projects in the FMCG manufacturing industry.

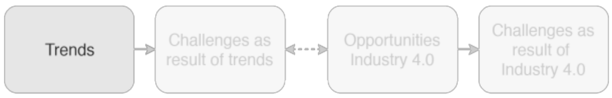


Figure 8-1 - Trends (Own figure, based on Davies & Sendler, 2018b)

The full PESTE analysis can be found in appendix G.1 (Table G-1) and will be referred upon in the next paragraphs about the changing consumer demands (Paragraph 8.2.1) and the changing manufacturing demands (Paragraph 8.2.2). The trends are coded related to the five different categories.

8.2 Challenges as Result of Trends

The trends established (Paragraph 8.1), provided information on the political, economic, social, technological and environmental change factors. This paragraph describes the changing consumer demands as result of the trends and the changing manufacturing demands as result of the changing consumer demands.

The trends identified and defined are linked to the changing consumer demands by measuring the impact of the trends on the four dimensions of consumer demands (i.e. specification, volume, moment and location). This is done based on qualitative and quantitative data on these trends, derived from literature of the United Nations and the World Bank. The changing consumer demands are linked to manufacturing demands by comparing the changes in the four different dimensions of the consumer demands, to the specific characteristics, components and spatial requirements of FMCG factories. The changing manufacturing demands result into possible challenges for the FMCG manufacturing industry.

The goal of linking the trends to the consumer demands and therefore to the manufacturing demands is to identify the possible challenges for the FMCG manufacturing industry (Paragraph 8.2.2), for which possible opportunities of Industry 4.0 (Paragraph 8.3) could be a solution (Figure 8-2). These challenges and opportunities therefore also affect construction projects in the FMCG manufacturing industry.

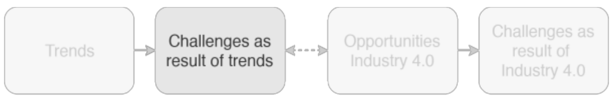


Figure 8-2 - Challenges as result of trends (Own figure, based on Davies & Sendler, 2018b)

This paragraph is divided into three sub paragraphs. The first paragraph describes the changing consumer demands (Paragraph 8.2.1) and in the second paragraph the changing manufacturing demands and the challenges for the FMCG manufacturing industry as result of these changes are described (Paragraph 8.2.2).

8.2.1 Changing Consumer Demands

This paragraph describes the changing consumer demands by describing the impact of the trends on the four dimensions of consumer demands:

- Specification: verifies *what* is demanded (e.g. type of goods, type of packaging, etc.)
- Volume: verifies *how much* is demanded (e.g. number of goods, size of packaging, etc.)
- Moment: verifies *when* the goods are demanded (e.g. specific moment in time, timeframe between demand and delivery, between demand and consuming, etc.)
- Location: verifies *where* the goods are demanded

- **Changing specification demands**

The following trends cause the changing specification of consumer demand (Appendix G.2; Table G-2):

- New legislation and regulation (P1)
- Growth of the circular economy (E4)
- “Servitisation” of demands (E6)
- “Healthification” of demands (S7)
- Growth internet driven connectivity (T2)
- Growth of social networks (T4)
- Rising awareness of climate change and link to energy solutions (EN4)

Consumers are demanding more transparency on the full journey of their goods (Kasriel-Alexander, 2012), caused by the rising awareness of climate change and the growth circular economy.

“Always online” (Fry et al. 2017, p. 2) and *“rise of digital consumer”* (Chatterjee, Küpper, Mariager, Moore, & Reis, 2011, p. 5) are quotes referring to the digitisation of the consumer demands during the last decade. The percentage of the population of individuals using the internet has grown, from less than

15% in 2005 and more than 45% in 2015 (The World Bank, 2016). This is one of the factors causing the digitisation trend. The proportion of online purchases has been growing over the last decade, also for FMCG. In two European countries researched, one-third of consumers did their FMCG purchases online already in 2011 (Chatterjee et al., 2011).

Moreover, the consumer demand is increasingly individualising. Which means the for example the customisation and personalisation of consumer goods, such as FMCG (Brettel et al., 2016; Kasriel-Alexander, 2012; Paritala, Manchikatla, & Yarlagadda, 2017; Zhong et al., 2017). The individualization is caused by the growth of the internet driven connectivity and the growth of social networks, because consumers this increases the choosing and comparing possibilities of consumers. The increasing variety in FMCG, is caused by the individualized consumer demands for FMCG (Fry et al., 2017).

- **Changing volume demands**

The following trends cause the changing volume of consumer demand (Appendix G.2; Table G-2):
- Growing affluence driven by expanding middleclass (E3)
- Growing population (S1)
- Aging population (S2)

The volume of the FMCG demand of the total population will increase due to the growing and aging of the population (Figure 8-3). The growth of the population has had a steep rate for many years and is expected to continue to grow from around 6 billion people in 2000 to almost 12 billion people in 2100. The median age of the population will raise 20 years (from 26 to 41 years) in the next 80 years (United Nations - Department of Economic and Social Affairs, 2017).

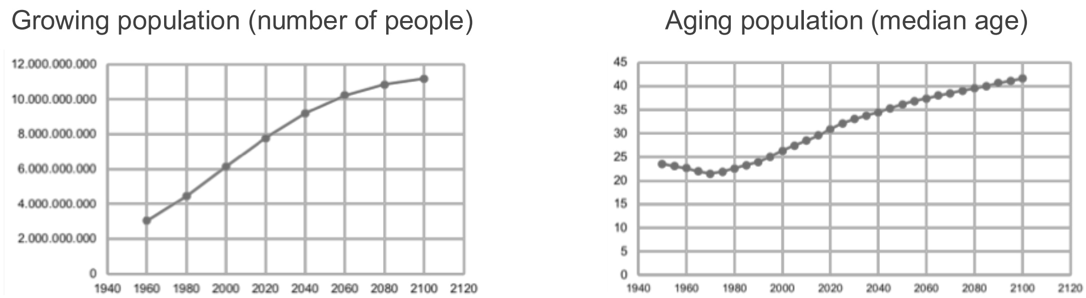


Figure 8-3 - Changing consumer demands - Increasing world population and median age (United Nations - Department of Economic and Social Affairs, 2017)

The size of the world's consuming class has doubled since 1990 till now and is still growing, expected an additional 1.8 billion people from 2015 to 2025 (Figure 8-4). The consuming class is defined as individuals with a disposable income of more than $10 a day. The sources of this growth are the population growth (Figure 8-3) and the per capita consumption growth. From 2015 till 2030 the per capita consumption growth is expected to be 75% of the consumption growth (Dobbs et al., 2016).

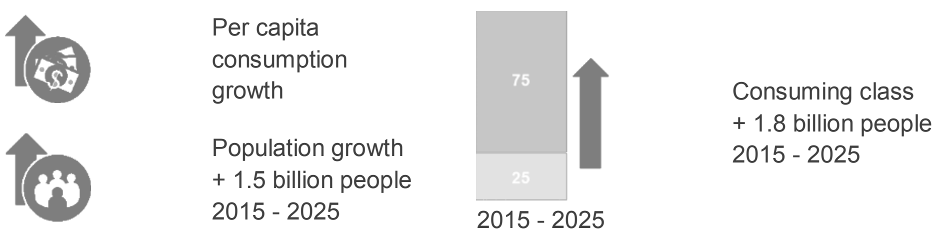


Figure 8-4 - Changing consumer demands - Growth of consuming class (Own figure, based on Dobbs et al., 2016)

- **Changing moment demands**

The following trends cause the changing moment of consumer demand (Appendix G.2; Table G-2):

- Immediate fulfilment of demands (E5)
- Growth internet driven connectivity (T2)
- Real time news (T3)
- Growth of social networks (T4)

Caused by the four trends described above, the pressure on the timeframe between the demand and delivery of the FMCG is high and increasing. Consumers demands fast, on-demand and 24/7 delivery, for low-priced, high-quality consumer goods (Fry et al., 2017).

- **Changing location demands**

The following trends cause the changing location of consumer demand (Appendix G.2; Table G-2):

- Widening inequality (E2)
- Continued urbanisation and depopulation rural areas (S3)
- Growth internet driven connectivity (T2)
- Growth of social networks (T4)

Due to the growth of the internet driven connectivity, the growth of social networks and the widening of the inequality, the locations of the consumer demand become more scattered and decentralised. However, on the other hand, due to the growing urbanisation and depopulation of rural areas, the locations of the consumer demand become more centralised.

8.2.2 Changing Manufacturing Demands and Challenges for the FMCG Manufacturing Industry

The change of manufacturing demands is identified by comparing the changes in the four different dimensions of consumer demands to the specific characteristics, components and spatial requirements of FMCG factories (Appendix G.2; Table G-2).

The characteristics of FMCG factories change by the influence several of a change in specification of consumer demands. Moreover, the components of FMCG factories change by the several specific changes in the specification, moment or location of the consumer demand. The spatial requirements of FMCG factories change by the influence of a specific changes in the consumer demands, related to the specification, volume, moment and location dimension of the consumer demands (Appendix G.2; Table G-2).

Furthermore, this paragraph describes the challenges for the FMCG manufacturing industry as result of the trends, causing changing consumer demands, causing changing manufacturing demands. For this research, a challenge can be described as a demanding situation caused by external threats, with a certain probability of occurring or not, which can also be called under uncertainty (Leijten, 2016).

The following challenges for the FMCG manufacturing industry are identified and will be described:

- Global competitiveness
- Time, cost and quality pressure
- Increasing demand for changeability
- Increasing demand for integration

- **Global competitiveness**

For multinational FMCG manufacturers, the globalisation of the FMCG manufacturing industry, can represent the opportunity to expand. However, the globalised manufacturing industry also leads to a greater global competitiveness, which leads to an increase in the volatility of costs and prices (Chatterjee et al., 2011). Moreover, this competitiveness is caused by the rise of the digital consumer. The rise of the digital consumer challenges the FMCG manufacturing industry in the field of understanding and connecting with consumers to enhance consumer involvement (Kasriel-Alexander, 2012).

Related to the growth of the volume and the change of location of the consumer demand, is the division into the global and local FMCG market. The global FMCG market is emerging, caused by the growing middle class in emerging markets. The local FMCG market is emerging, caused by the specific local consumer demands (Hermann et al., 2016). Fry et al. (2017, p. 2) stated *"be global and be local"*, which means FMCG manufacturers should focus on both the both the global and local emerging markets.

- **Time, cost and quality pressure**

Fry et al. (2017, p. 2) stated *"be more efficient and be smarter"*. As the global competitiveness increases, it becomes increasingly important for FMCG manufacturers to manufacturer their goods fast, against low prices and with superior quality. The manufacturing demand changes to producing and delivering as fast as possible (Kasriel-Alexander, 2012), by short lead-times of goods and on-demand delivery (Zhong et al., 2017). The manufacturing challenge is to manufacturer do all of this in an efficient and smart way (Brettel et al., 2016).

- **Increasing demand for changeability**

Herrmann et al (2014, p. 283) state: *"the desire for new individualized goods make manufacturing more challenging than ever"*. Since the FMCG manufacturing produces high volumes generally (Fry et al., 2017), the decreasing volume per specific good and the increasing variety of goods (Hermann et al., 2016), is challenging for its manufacturing environments. The decreasing volume per specific good and the increasing variety are caused by current and new trends, such as individualisation, personalisation and customisation of goods. These new trends cause the FMCG manufacturer's demand for increased changeability (Fry et al., 2017; Hermann et al., 2016; Mourtzis, Papakostas, Makris, Xanthakis, & Chryssolouris, 2008). The manufacturing challenge related to increased changeability, is different goods all have different manufacturing processes (Hermann et al., 2016).

In order to be able to manufacturer the bigger variety of FMCG, under the time, cost and quality pressure, new information and manufacturing strategies and techniques are needed as enablers (Davies & Sendler, 2018b; Zheng, Xu, Yu, & Liu, 2017).

- **Increasing demand for integration**

Related to the consumers demanding transparency, is the increasing demand for integration. Specifically, the horizontal integration and end-to-end integration, meaning the different actors and processes within the value chain are integrated (Zhou & Liu, 2016). These consumer's transparency demand and the integration of the value chain are related, so consumers have better insights in the value chain of the goods (Zhong et al., 2017).

8.3 Opportunities Industry 4.0

The challenges for the FMCG manufacturing industry, established in the last paragraph (Paragraph 8.2.2), ask for possible solutions. Since challenges, caused by external threats, entail uncertainty, the solutions to these challenges could also entail uncertainty. Opportunities are external chances with the means to improve. Opportunities can be exploited to eliminate challenges.

This paragraph identifies and defines the opportunities of Industry 4.0, as possible solutions for the challenges in the FMCG manufacturing industry, based on a literature review. Industry 4.0, also called the fourth industrial revolution, was introduced in the research context (Paragraph 1.1.1).

Since the opportunities of Industry 4.0 should function as possible solutions for the challenges for the FMCG manufacturing industry, the opportunities are linked to these challenges based on the criterium of eliminating the challenge. Moreover, the link between the opportunities of Industry 4.0 to construction projects in the FMCG manufacturing industry is made.

The goal of identifying and defining the opportunities of Industry 4.0 (Figure 8-5), is the first step in defining the strategic vision on the future of the FMCG manufacturing industry and the design of future-proof construction projects in the FMCG manufacturing industry (Chapter 9).

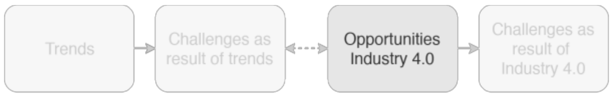


Figure 8-5 - Opportunities Industry 4.0 (Own figure, based on Davies & Sendler, 2018b)

The paragraph is divided into three sub paragraphs, according to the different themes of the sub research questions. The first paragraph describes the trends of Industry 4.0 (Paragraph 8.3.1). The second paragraph describes the technologies of Industry 4.0 (Paragraph 8.3.2) and in the third paragraph the design concepts related to the FMCG manufacturing industry in the context of Industry 4.0 are described (Paragraph 8.3.3).

8.3.1 Trends Industry 4.0

Davies and Sendler (2018b) state Industry 4.0 should be seen as a fundamental transformation of the entire value chain of industrial manufacturing and not as simple changes of singe parts of the value chain. For establishing this fundamental transformation of the entire value chain, firstly, a division is made between cyber and physical trends. For this research, cyber trends are defined as impacting the digital and virtual world, where as physical trends are defined as impacting the physical world (Hermann et al., 2016).

Cyber trends

Hook et al. (2016) identified data acquisition and analytics as the core capabilities of Industry 4.0. Lee et al. (2015, p. 19) described the two trends related to these concepts:

- *“The advanced connectivity that ensures real-time data acquisition from the physical world and …*
- *Intelligent data management, analytics and computational capability that constructs the cyber space.”*

Data acquisition is collecting data. Data in manufacturing environments can be divided into time dependent data and time independent data (Table 8-1), which ask for real-time data acquisition and non-real-time acquisition, respectively. Data analytics is processing and modelling the data acquired to convert into information (Lee, Bagheri, & Kao, 2015b).

Types of data	Examples	Data acquisition
Time dependent data	Production flow	Real-time data acquisition
	Movement of employees	
	Machine assignment	
	Transport routes	
Time independent data	Ground plan	Non-real-time data acquisition
	Layout	
	Purpose of production machine	
	Parts list	
	Qualification of employees	
	Shifts of employees	

Table 8-1 - Trends Industry 4.0 - Types of data related to data acquisition (Uhlemann, Lehmann, & Steinhilper, 2017)

More specifically, in the manufacturing industry, the production flow, which is a type of dependent data, consists of information on raw material composition, detailed product characteristics specifications, heat (i.e. energy) and material (i.e. mass) balances for every step in the production flow, etc. (Merrow, 2011).

Moreover, the importance of developing capabilities related to data acquisition and data analytics, to enhance the potential of Industry 4.0, is stressed by numerous other management and scientific researchers (Freige, Hammer, Ulrich, Lacovelli, & Bromberger, 2016; Liu & Xu, 2016; Uhlemann et al., 2017).

In the FMCG market, the enhancing data acquisition and data analytics, could mean linking the demand of the FMCG value chain directly to the production flow in the FMCG market. This could, for example, eliminate the manufacturing challenges related to immediate fulfilment of demands. Enhancing data acquisition and data analytics in FMCG factories starts in the construction projects of these factories. All data regarding the design and engineering of the factory could be acquired (time independent data) and certain techniques for acquiring time dependent data could implemented in the design and engineering of the factory.

Physical trends

Also, Industry 4.0 is characterised by trends in the physical world, two main trends can be distinguished: conversion to the physical world and human-machine interaction (Freige et al., 2016).

The flow of conversion to the physical world works by the following steps. Firstly, data is processed and modelled to provide information. By identifying value drivers, insights can be extracted from the information. Secondly, an action plan can be derived from these insights and actions can create an impact. The data and information part of this flow are technology driven and part of the cyber trend. Insights are the first step of the conversion to the physical world by causing people-driven actions and impact (Freige et al., 2016). Moreover, by enhanced cooperation among human and machines, human and machines will be able to pursue the manufacturing objective in an effective and efficient way (Rüßmann et al., 2015).

Cyber and physical trends

With the combination of the cyber and physical trends the opportunities of Industry 4.0 can be enhanced. The following sequence of the four trends can be seen as a step-by step approach: firstly data acquisition, secondly data analytics, thirdly conversion to the physical world and fourthly human-machine interaction (Freige et al., 2016; Liu & Xu, 2016).

8.3.2 Technologies Industry 4.0

The four trends of Industry 4.0, established in the last paragraph, provided information on the step-by-step approach for enhancing the opportunities of Industry 4.0. The technologies in the context of Industry 4.0 are clustered and linked to the four trends (Table 8-2). In appendix G.3 (Table G-3), the full overview of the review of management literature and clustering of trends can be found (Freige et al., 2016; Hook et al., 2016; Küper et al., 2013; Scalabre, 2018).

Trends	Technologies
Increasing data acquisition, computational power and connectivity	Big data acquisition technologies
	Internet of things
	Cloud technology
	Cybersecurity technologies
Increasing data analytics and intelligence	Advanced analytics systems
	Artificial intelligence systems
Increasing advanced conversion to the physical world	Additive manufacturing
	Advanced robotics technologies
Increasing advanced human-machine interaction	Augmented reality
	Simulation
	Advanced design technologies

Table 8-2 - Technologies Industry 4.0 - Trends linked to technologies (Küper et al., 2013; Scalabre, 2018)

In this paragraph the identified technologies are described.

Big data acquisition technologies (e.g. sensors, RFID tags)

The acquisition of large amounts of physical data, from time dependent and time independent sources of the manufacturing system, as well as digital data, e.g. company- and consumer data can be done by the use of advanced technologies, such as sensors and RFID tags (Scalabre, 2018).

Internet of Things (i.e. IoT platforms)

Data sources can be interconnected and can be connected to the internet to create real-time data as input for IoT platforms. Interacting work pieces, machines and people can be centrally controlled through the IoT platform and create an autonomous manufacturing process in a decentralised matter (Küper et al., 2013; Scalabre, 2018).

Cloud technology

Cloud technology is the infrastructure for computing, i.e. capture and store, the big data acquired. Enablers for cloud computing are network standards and a network infrastructure. Cloud computing enables the connectivity on a central platform of decentralised data (Küper et al., 2013), so data can be shared across physical locations (e.g. manufacturing and construction sites) and companies (Rüßmann et al., 2015). Moreover, the systems that monitor and control the data can become cloud based as well. Cloud technology is closely the related to the IoT platforms.

Cybersecurity technologies (e.g. authentication and fraud detection)

The increased connectivity, enabled by IoT platforms and cloud technology, leads to essential sophisticated cybersecurity technologies. Examples are advanced authentication technologies and advanced fraud detection technologies. These technologies enable sophisticated identity and access management and reliable communication methods (Scalabre, 2018). Cybersecurity companies and industrial process machinery and equipment are developing are joining forces to continuously develop these advanced technologies (Rüßmann et al., 2015).

Advanced analytics systems

Advanced analytics systems enable optimisation of manufacturing processes, by gathering and evaluating the big data acquired and converting it into information and insights to support real-time decision-making (Rüßmann et al., 2015).

Artificial intelligence systems

At the most basic level, artificial intelligent (AI) is the concept of machines doing tasks for which historically human intelligence was required. The concept can be subdivided into applied AI, machines designed to complete very specific tasks, and general AI, machines designed to complete any task (as described above) and learn by encountering new tasks and situations (i.e. machine learning) (Yao, Zhou, Zhang, & Boër, 2017). Machine learning is the process of building algorithms which can learn and train themselves by accessing, applying algorithms to, and gain insights from, big data. Deep learning takes AI and machine learning a step further, by simulating the human brain artificially (Yao et al., 2017).

Additive manufacturing (e.g. 3D printing)

Additive manufacturing enables the changeability of manufacturing systems and design optimisations, by being able to manufacturer complex and individualised goods (Sol, 2018). A common additive manufacturing technology is 3D printing, which can be used for liquid, powder and solid materials manufacturing (Küper et al., 2013). Moreover, additive manufacturing in combination with advanced design technologies will enhance the possibility of the increased optimisation and changeability.

Advanced robotics technologies

Advanced robotics technologies enable smart, self-learning, autonomous and collaborative robots to optimise the manufacturing systems. Smart and self-learning robots are able to perform tasks that are more complex than humans are able to perform. Moreover, while performing, the self-learning mechanisms of the robots can learn by collecting data from each work piece, analysing it and using the information to automatically adjust its actions to the specific characteristic of the specific task (Küper et al., 2013). Autonomous robots are to perform their task autonomyously, without the need of human, machine or (other) robot intervention. Collaborative robots are able to collaborate with and support humans, machines and other robots (Küper et al., 2013).

Augmented reality

The technology of augmented reality enables advanced human-machine interfaces. By the real-time information provision, improvement of decision-making and other procedures is possible. For example, through smart classes an extra layer of information can be projected on the physical reality (Küper et al., 2013).

Simulation (e.g. virtual reality)

Simulations based on representations of the physical world combined with real-time data can be used to optimise processes, e.g. 3D representations combined with real-time data on processes and flows of machines, products and humans. The physical world mirrored in a virtual model, allows to test and optimise the physical world without physical changeovers (Scalabre, 2018). Realistic training methods can be developed by the use of 3D simulations (Küper et al., 2013).

Advanced design technologies (e.g. CAD, BIM, parametric design)

Computer-aided design (CAD), building information modelling (BIM), 5D BIM (3D model including planning and budget) and parametric design are examples of advanced design technologies enabled by different technologies described before in this paragraph. These technologies enable the simulation of physical objects, instead of the simulation of processes, as described in the last paragraph (Küper et al., 2013; Scalabre, 2018).

8.3.3 Design Concepts Industry 4.0

The trends of Industry 4.0 (Paragraph 8.3.1) and technologies of Industry 4.0 (Paragraph 8.3.2), established the information to identify and define three design concepts related to the FMCG manufacturing industry in the context of Industry 4.0. In this paragraph, the following design concepts will be described: cyber-physical manufacturing, smart manufacturing and modular manufacturing (Figure 8-6) (Hermann et al., 2016; Li et al., 2018; Thramboulidis, 2015).

Cyber-physical manufacturing (Thramboulidis, 2015) | Smart manufacturing (Li et al., 2018) | Modular manufacturing (Hermann et al., 2016)

Figure 8-6 - Design concepts Industry 4.0
(Own figure, based on Hermann et al., 2016; Li et al., 2018; Thramboulidis, 2015)

The three concepts were selected by considering their operational and physical impact on manufacturing environments (Verter & Cemal Dincer, 1992). These two dimensions of impact are chosen, because they entail the delivering of a FMCG demand (i.e. the operational domain) by a FMCG factory (i.e. the physical domain).

The selection of the three concepts considering their impact is done to enhance the opportunities of Industry 4.0. The three concepts focus on specific technologies, rather than focusing on all technologies in the context of Industry 4.0 at the same time (Table 8-3). This is supported by Breunig et al. (2016, p. 2):

"Manufacturers should focus on a limited number of Industry 4.0 applications, rather than trying to cover all levers at once." (Breunig et al., 2016, p. 2)

Trends	Technologies	Design concepts		
Increasing data acquisition, computational power and connectivity	Big data acquisition technologies	Cyber-physical		Modular
	Internet of things			
	Cloud technology			
	Cybersecurity technologies			
Increasing data analytics and intelligence	Advanced analytics systems		Smart	
	Artificial intelligence systems			
Increasing advanced conversion to the physical world	Additive manufacturing			
	Advanced robotics technologies			
Increasing advanced human-machine interaction	Augmented reality			
	Simulation			
	Advanced design technologies			

Table 8-3 - Opportunities Industry 4.0 - Design concepts Industry 4.0 - Overview of trends and technologies related to design concepts

Concept 1: Cyber-Physical Manufacturing

Cyber-physical manufacturing is manufacturing by the use of the combination of cyber and physical systems. Cyber systems are digital and virtual and are steered by time-dependent and time-independent data of the physical system. Physical systems are all systems physically present in the factory, e.g. physical manufacturing systems, physical logistical systems, etc. (Hermann et al., 2016).

Cyber-physical systems can be described by the steps taken from data to (Baena, Guarin, Mora, Sauza, & Retat, 2017; Paritala et al., 2017):

1. Sources of data
2. Technologies to acquire data
3. Data transfer
4. Consolidation of data
5. Data-to-information conversion
6. Information management
7. Visualisation of information

These steps can be related to the infrastructure needed for each step (Baena et al., 2017). Moreover, the these steps can be related to the three different levels of physical objects, the cloud and services (Drath & Horch, 2014), and to the physical and cyber domain (Landherr, Schneider, & Bauernhansl, 2016). In appendix G.3 (Table G-4) the overview of the relations can be found. The infrastructures supporting the steps realising cyber-physical manufacturing are built up by Industry 4.0 technologies. Although these technologies are already available, many are not yet implemented on large scale yet. The aim of cyber-physical manufacturing can be described two folded (Uhlemann et al., 2017):

- Realising transparency in the production system
- Real-time production control

In appendix G.3 (Table G-5) an overview of the goals related to the current state of scientific knowledge and the problems can be found (Uhlemann et al., 2017). Moreover, these problems are linked to future systems for multi-model data acquisition to solve these problems and reach the goals of cyber-physical manufacturing. The problem of manually collected data can be solved by collecting data through sensors. The problem of decentralised data can be solved by the use of transferring and consolidating all data in one central cloud.

From all information collected on cyber-physical systems, an overview of cyber systems, focusing on data and information, and physical systems, focusing on manufacturing, is made for FMCG factories (Table 8-4).

The benefits of using cyber-physical systems for the output of construction projects in the FMCG manufacturing industry, i.e. FMCG factories, are stressed by different researchers (Thramboulidis, 2015; Um, Weyer, & Quint, 2017; Weyer, Schmitt, Ohmer, & Gorecky, 2015). One of the benefits could be increased integration in the FMCG factory. Increased integration can be realised by the integration of all physical and cyber systems through the different steps from data sources to information visualisation.

Cyber Systems		Physical Systems	
Data and information		Manufacturing	
Steps	Technologies	Categories	Technologies
Data sources	Sensors, RFID [1]	Robotics	Autonomous
Data collection	Smart sensoring		Self-learning
Data transfer	Internet of Things		Interaction
Data protection	Cyber security	Additive manufacturing	3D-printing
Data-to-information	Big Data Analytics		
Information management	ERP [2], MES [3], PLM [4], CRM [5]		
Information visualisation	Mobile applications, screens, touchscreens, smart boards		
Cyber-physical systems			
System Integration - From FMCG plant to FMCG retailer			
Simulation - Real-time operations			
AR [6], VR [7], real-time and interactive dashboards			

[1] RFID = Radio frequency identification
[2] ERP = Enterprise resource planning
[3] MES = Manufacturing execution systems
[4] PLM = Product lifecycle management
[5] CRM = Customer relationship management
[6] AR = Augmented reality
[7] VR = Virtual reality

Table 8-4 - Design concepts Industry 4.0 - Cyber-physical manufacturing - Design cyber and physical systems

Concept 2: Smart Manufacturing

Smart manufacturing *"aims to take advantages of advanced information and manufacturing technologies to enable flexibility in the physical processes to address a dynamic and global market"* (Li et al., 2018, p. 92). Smart manufacturing entails the increased manufacturing intelligence by advanced analytics systems and artificial intelligence systems. Moreover, it entails converting the increased intelligence autonomously into the physical world by additive manufacturing and advanced robotics technologies.

For implementing a smart manufacturing system, the life cycles of the three dimensions of the smart manufacturing ecosystem should be considered: product, production and business life cycles (Table 8-5) (Li et al., 2018).

Smart Manufacturing Ecosystem (SME) - Life cycles of three dimensions	
Product	Product lifecycle from design, process planning, production engineering, manufacturing, use and service to recycling
Production	Production lifecycle (of entire factory) from initiation, design, construction to exploitation and maintenance
Business	Supply chain cycle from plan, source, make, deliver to return

Table 8-5 - Design concepts Industry 4.0 - Smart Manufacturing - Smart Manufacturing Ecosystem (SME) (Li et al., 2018)

The production lifecycle of entire factories from initiation to exploitation and maintenance is related to the construction projects of factories. For implementing a smart manufacturing system in the output of construction projects in the FMCG manufacturing industry, standardisation is needed. For example, standardised building blocks (i.e. components) (Paragraph 7.2.2) and standardised spatial requirements (Paragraph 7.2.3) can help making the implementation of smart manufacturing easier and less time- and cost-consuming (Li et al., 2018).

Related to smart manufacturing are the concepts of intelligent, IoT-enabled and cloud manufacturing. The description of these concepts, their characteristics and the supporting Industry 4.0 technologies related to the concepts can be found in appendix G.3 (Table G-6) (Zhong et al., 2017). These concepts are related to the general concept of smart manufacturing, because all three concepts focus on advanced analytics and the advanced conversion from the physical world.

Smart machines could be used as smart manufacturing system in the output of construction projects in the FMCG manufacturing industry. The machines would make decisions themselves by communicating with each other and with the so-called smart goods. However, further research on the autonomous manufacturing system architecture is needed (Wang et al., 2016).

Concept 3: Modular Manufacturing

Modularised manufacturing can be described as multiple manufacturing units working together within the same integrated system. These units should be smart and transportable, so the location of the units and the routes between the units can easily change (Wang et al., 2016).

With the emerging trend of individualised, personalised and customised goods, FMCG manufacturers call for an highly changeable physical factory infrastructure (Hermann et al., 2016), for which the concept of modular manufacturing can offer a solution.

The concept of modular manufacturing is strongly related to the concept of changeability. The design principles enabling changeable manufacturing have been defined as modularity, scalability, universality, compatibility and mobility by Wiendahl et al. (2006; 2007). These design principles can be used when designing the an adaptive building shell, modular and scalable technical building services, i.e. utilities and a changeable manufacturing system (Herrmann et al., 2014). Together, these form a modular manufacturing unit.

The building shell serves the technical building services and the manufacturing systems and is often not primarily designed. However, the changeability of building shell enables the changeability of the whole factory system (Hermann et al., 2016). On the other hand, the building shell can constrain the changeability of the whole factory system when not designed for changeability. The building shell is determined by the primarily structure of columns, walls and floors. All structures can be more adaptive to changing requirements by the realisation of new building concepts, such as containers, air-inflated structures, etc. (Hermann et al., 2016).

For enabling the changeability of the FMCG factory, the technical building services should be physically and virtually linked to the manufacturing systems of the factory. Also, the technical building services will play a significant role connecting the inner and outer factory flows of utilities. Moreover, the technical building services must enable the manufacturing of individualised, personalised and customised goods. Modular, expandable and decentralised structures of the technical building systems, based on the concept of plug-and-produce, will enable the needs of the factory of the future (Hermann et al., 2016).

The time-to-market of FMCG should be as short as possible, whilst the manufacturing systems remains cost-effective and produces high quality products (Kasriel-Alexander, 2012; Zhong et al., 2017). The high degree of machine utilisation should enable modular manufacturing systems to manufacturer high quality FMCG, in a time and cost efficient way (Hermann et al., 2016).

8.4 Challenges as Result of Opportunities of Industry 4.0

The opportunities of Industry 4.0 established (Paragraph 8.3), could result into a transition and therefore into possible new challenges. This paragraph describes the way of dealing with a transition, by exploring the ways of establishing a transition roadmap to guide future actions

This is done by a review of scientific literature on change management and dealing with uncertainty, which will result into criteria for the transition roadmap (Paragraph 8.4.1). Moreover, management literature is reviewed on transition roadmaps within the context of Industry 4.0, which will result into a concept design for the transition roadmap (Paragraph 8.4.2).

The goal of exploring the ways of establishing a framework is the first step in finding a way to deal with the challenges as result of the transition (Davies & Sendler, 2018b). The combined strategic vision on the future (Chapter 9) and the transition roadmap (Chapter 10), i.e. the commitment to short-term actions, could be a way of dealing with the challenges of the transition (Haasnoot, Kwakkel, Walker, & ter Maat, 2013).

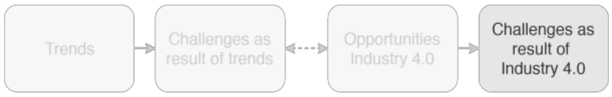


Figure 8-7 - Challenges as result of the opportunities of Industry 4.0 (Own figure, based on Davies & Sendler, 2018b)

8.4.1 Criteria Transition Roadmap

A transition is defined as the process of changing form one situation to another (Ewenstein, Smith, & Sologar, 2015). For this research, the transition is defined as the change from the current to the future situation of construction projects in the FMCG manufacturing industry. This transition is caused the opportunities of Industry 4.0, caused by the challenges, caused by trends.

Coping with change, i.e. the transition, is challenging (Ewenstein et al., 2015). Haasnoot et al. (2013) describe that dealing with a transition in a deep uncertain and continuously developing environment, can be done by creating a strategic vision on the future, commit to short-term actions, and establish a framework to guide future actions.

The criteria for describing the short-term actions are identified the action being: specific, measurable, achievable, relevant and time-bound (SMART) (Bjerke & Renger, 2017). However, since the key trends and technologies in the context of Industry 4.0 are continuously developing, the transition roadmap should react to these changes. For the transition roadmap to be changeable, the roadmap could be used iteratively by cycles of plan, design, build, test and review (Hoda, Noble, & Marshall, 2008).

8.4.2 Concept Design Transition Roadmap

In appendix G.4 (Table G-7) the comparison of transition roadmaps within the context of Industry 4.0 from three different management researches can be found. This comparison is used as concept design for the transition roadmap from the current to the future situation of construction projects in the FMCG manufacturing industry.

Moreover, the following aspects regarding change management can be considered in the design of the transition roadmap. Firstly, the involvement of change agents that feel ownership over the change, can help during the implementation process (Oesterreich & Teuteberg, 2016). Secondly, individuals with the right capabilities can be enhanced by showing them the purpose of the change. And thirdly, for changing the behaviour of individuals, a rewarding recognition system helps (Ewenstein et al., 2015).

Data Analysis

(Picture Royal HaskoningDHV, case study project 2B in Pakistan)

Data Analysis

The fourth part of this thesis, the data analysis, presents the data analysis of all data collected, in three chapters. The first chapter presents the design of the future situation (Chapter 9) and in the second chapter the design of the transition roadmap from the current to the future situation is presented (Chapter 10). The third chapter presents the validation of both designs (Chapter 11).

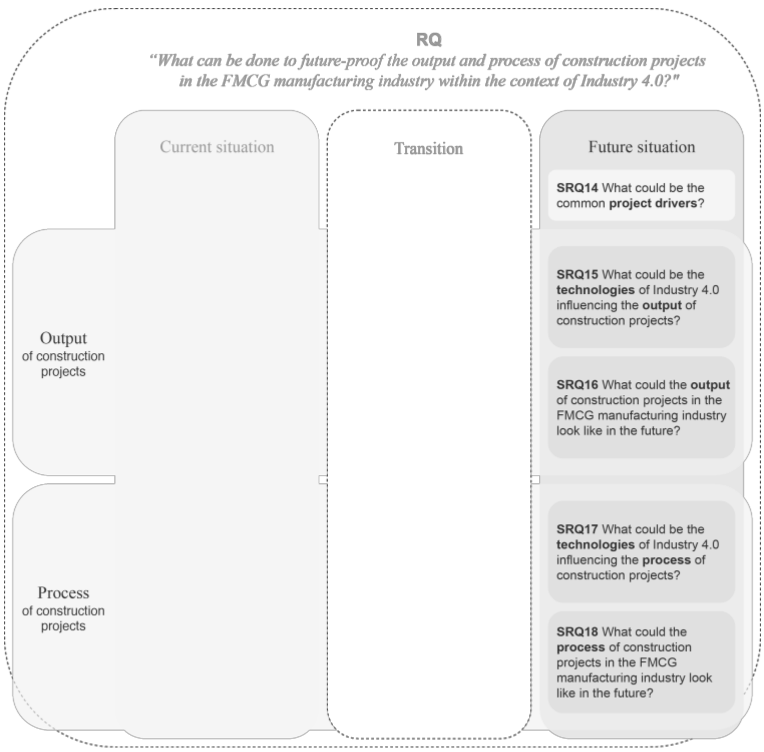
9

Design Future Situation

This chapter presents the design of future-proof construction projects in the FMCG manufacturing industry. The chapter is divided into three paragraphs, according to the different themes of the sub research questions. The first paragraph describes the future project drivers (Paragraph 9.1). The second paragraph describes the future output (Paragraph 9.2) and in the third paragraph the future process is described (Paragraph 9.3).

For the design of the future situation, it is important to realise the exploratory nature of this research. Since the design of the future situation is in the context of the rather new trend of Industry 4.0, it is not aimed to compose a strict to design, rather provide insights and a vision that could be further developed in future research.

Moreover, the key opportunities of Industry 4.0 (Paragraph 8.3) are continuously developing. Therefore, the link of these opportunities to the output and process of construction projects is probably also continuously changing.



In general the concept of Industry 4.0 has not gained much in attention in the construction industry (Dallasega et al., 2018; Oesterreich & Teuteberg, 2016). Moreover, no theories are available on the current output and process of construction projects in the FMCG manufacturing industry. Therefore, the analysis in this paragraph is based on the combination of the findings of the current situation of construction projects in the FMCG manufacturing industry (Chapter 7) and the transition (Chapter 8).

9.1 Future Project Drivers

This paragraph describes the design of the future project drivers of construction projects in the FMCG manufacturing industry. Rüßmann et al. (2015) state the importance of the identification of key areas for improvement, which can be translated to clear project drivers for construction projects. The paragraph is divided into two sub paragraphs. The first paragraph describes the pressure on the traditional project drivers (Paragraph 9.1.1) and in the second paragraph the introduction of additional project drivers is described (Paragraph 9.1.2).

9.1.1 Pressure on Traditional Project Drivers

In paragraph 7.1, the pressure on the traditional project drivers of time, cost and quality, within a fixed scope, is described, causing several challenges and problems for the output (Paragraph 7.2.4) and process (Paragraph 7.3.4) of construction projects in the FMCG manufacturing industry. Moreover, in paragraph 8.2.2, the pressure on these project drivers is identified as a challenge named as a challenge for the FMCG manufacturing industry, related to the increasing competitiveness in the industry.

The trends (Paragraph 8.3.1) and technologies (Paragraph 8.3.2) in the context of Industry 4.0 can increase the efficient use of time and budget. Therefore, enhancing Industry 4.0 trends, by implementing Industry 4.0 technologies in construction projects in the FMCG manufacturing industry can help to meet the pressure related to the traditional project drivers. For the output, i.e. the FMCG factory, the manufacturing process becomes faster, cheaper and produces high quality products by the introduction of Industry 4.0 technologies.

For the process, for example, advanced analytics can help to speed up complex decision-making processes in the initiation phase of construction process. The advanced human-machine interaction technologies, such as augmented reality and advanced design technologies helps to speed up the design phase of the process. Moreover, additive manufacturing and advanced robotics technologies can speed up and lower the costs of the process of construction projects in the FMCG industry. Additive manufacturing can be used to manufacture supplier parts. Advances robotics can be used to assemble these parts into a manufacturing facility (i.e. the building).

9.1.2 Introduction of Additional Project Drivers: Changeability and Integration

For the future situation, changeability and integration (both concepts defined in paragraph 7.3.4) are introduced as additional project drivers. Both the output and process of construction projects in the FMCG manufacturing industry were characterised by problems and challenges related to limited changeability and limited integration. To remain competitive, FMCG manufacturers could focus on changeability of and integration in both the output and process of construction projects in the FMCG manufacturing industry (Davies & Sendler, 2018b; Wang et al., 2016; Zhou & Liu, 2016).

The importance of changeability related to Industry 4.0 is stressed (Davies & Sendler, 2018a) and changeability can be defined as the combination of adaptability and flexibility and is the system's ability to adjust to changes in its internal or external environment (Wiendahl et al., 2007). Moreover, the importance of three different types of integration are related to Industry 4.0 (Wang et al., 2016; Zhou & Liu, 2016): horizontal integration is the integration of actors within the value chain, vertical integration is the integration of disciplines within an actor and end-to-end integration is the integration of the processes in the value chain and phases in construction projects.

Changeability of output

FMCG manufactures strive to answer the consumers demand of highly individualised, customised and personalised goods, in a time- and cost-efficient way (Zheng et al., 2017). This could be realised by increasing both the changeability of the manufacturing system and the facility of the FMCG factory. For the changeability of the manufacturing system, Industry 4.0 manufacturing techniques such as additive manufacturing and advanced robotics technologies can be used. Moreover, for the changeability of the facility of the FMCG factory, the concept of modular manufacturing can be considered.

Changeability of process

For the FMCG manufacturing industry specifically, changeability is an important additional project driver, because it helps answering the need to be able to answer the continuously changing consumer demands (Davies & Sendler, 2018b). In the process of construction projects in the FMCG manufacturing industry, the continuously changing consumer demands cause a continuous feedback loop to the business case (Case study interview, 6th of June 2018). To increase the changeability of the process, the possibility of building a so-called eco-system of service and product suppliers around the FMCG manufacturer can be considered (Exploratory interview, 8th of May 2018 - 1). The term eco-system is used, to describe close collaboration between the suppliers. An eco-system can help decreasing the complexity of the project organisation and therefore, increase the changeability during the process of construction projects in the FMCG manufacturing industry.

Integration in output

Currently, the FMCG value chain is not horizontally integrated. Suppliers of raw materials, FMCG manufacturers, FMCG retailers and consumers are rarely closely linked (Rüßmann et al., 2015). The integration of manufacturing processes, logistic processes and the actors related to these, can enable a value chain in which demand and supply are linked automatically (Scalabre, 2018). The future value chain could be realised by real-time communication across the process in the value chain among actors, machines, and goods (Rüßmann et al., 2015).

Horizontal, vertical and end-to-end integration related to the output and process could be realised by the use of an integrated systems for all data, documentation and communication (Oesterreich & Teuteberg, 2016; Parrott & Lane, 2017).

Integration in process

In the future situation, the end-to-end integration of the process of construction projects in the FMCG manufacturing industry could help to eliminate the challenges related to trends and exploit the opportunities of Industry 4.0. Integration throughout the whole process, from initiation to exploitation and maintenance and horizontal integration between all actors involved in the project organisation could be realised.

Horizontal integration can be enabled by the digitisation of the construction supply chain. In large-scale construction projects there can be numerous project participants and even many without physical proximity to the construction site. The use of technologies from Industry 4.0 can help for enhanced collaboration, communication and horizontal integration. Examples are a cloud-based collaboration environment and the use of BIM (Oesterreich & Teuteberg, 2016).

End-to-end integration can be enabled by the digitisation of phase associated processes and procedures, such as deliverables, milestones, etc. (Aconex & Boston Consulting Group, 2017).

9.2 Future Output

This paragraph describes the design of the future output of construction projects in the FMCG manufacturing industry. The paragraph is divided into four sub paragraphs, according to the different themes of the sub research questions. The first paragraph describes the characteristics of the future output (Paragraph 9.2.1). The second paragraph describes the components of the future output (Paragraph 9.2.2). The third paragraph describes the spatial requirements (Paragraph 9.2.3) and in the fourth paragraph the challenges of the future output are described (Paragraph 9.2.4).

9.2.1 Future Characteristics

The FMCG factory of the future could be characterised as integrated, smart and/or modular (Paragraph 8.3.3). Firstly, integrated, if all factory systems are integrated, by implementing cyber-physical systems (Thramboulidis, 2015). Secondly, smart, if the manufacturing processes are autonomously steered, enabled by big data acquisition, advanced analytics and interconnectedness of all systems in the factory (Li et al., 2018). Thirdly, modular, if multiple, smart and transportable manufacturing units work together in the same integrated system (Hermann et al., 2016).

Moreover, by implementing the design concepts of cyber-physical, smart and/or modular manufacturing, the demands of high delivery reliability and short delivery time of the FMCG market (Table 7-4) (Van Donk, 2001), can be met by the FMCG factory of the future. Also, the manufacturing challenges related to the low predictability and the specificity of the demand of the FMCG market (Van Donk, 2001), can be overcome by implementing the design concepts.

9.2.2 Future Components

The components of the FMCG factory of the future will stay similar to the current situation (Paragraph 7.2.2). However, the dimensions of several components will be different. The integration of the cyber systems with the physical systems will reduce the dimensions of the warehousing component, because less room for the stock of goods is needed. This is caused by the shorter time-to-market of the manufacturing and the enabling on-demand manufacturing (Um et al., 2017; Weyer et al., 2015). Moreover, the overall dimensions of masterplans and factories will be different, since smart and modular manufacturing systems enable decentralised manufacturing (Hermann et al., 2016; Li et al., 2018).

9.2.3 Future Spatial Requirements

Related to the dimensions of the manufacturing facility layout (Paragraph 7.2.3; Appendix E.1.1; Table E-2) (Drira et al., 2006) the following choices for the design of future FMCG factories help enhancing the opportunities of Industry 4.0 possibilities:

- By grouping the facilities with similar functions together, following a so-called process layout (Figure 7-1), the demand of the big and increasing variety of goods can be met
- By organising a logical sequence of building blocks, backtracking and bypassing of the good's flow can be minimised (Figure 7-2) and an autonomous flow of goods can be stimulated

The flow of goods through the factory can be autonomous, by implementing the concept of smart manufacturing. The smart facility, the smart manufacturing process (i.e. smart machinery and smart equipment) and smart goods are interconnected (Wang et al., 2016). Moreover, the interchangeable line modules could enable the changeability of the manufacturing system (Küper et al., 2013).

Regarding the architectural spatial requirements (Wiendahl et al., 2007), FMCG factories of the future are expected to need less surface (m^2), due to the decreasing of good's stock that needs to be warehoused and due to the decreasing number of people working in the factory by the implementation of advanced robotics technologies. However, designing with tolerances related to the surface and other spatial requirements could increase the changeability of the FMCG factory.

9.2.4 Benefits and Challenges

The design of the future situation of the output of construction projects in the FMCG manufacturing industry has certain benefits when compared to the current situation of the output (Paragraph 7.2). However, since the trends, technologies and concepts related to Industry 4.0 are rather new, there are also possible challenges implementing these in FMCG factories.

Benefits

The main benefit of the design for the FMCG factory is the ability to answer the continuously changing and individualised consumer demands for FMCG. The ability to answer in means of time- and cost-efficient manufacturing of high quality goods (Rüßmann et al., 2015).

Moreover, consumer centricity and continuous improvement can be enhanced by the implementation of digital technologies. Manufacturers can gain better understanding of consumers demands by the use of big data acquisition and advanced analytics, and are able to answer these demands rapidly by the integration of systems and advanced manufacturing technologies (Küper et al., 2013).

Challenges

In general, because of the newness of most technologies, the application of them in existing or new FMCG factories is challenging.

Related to the cyber-physical manufacturing, the autonomous data acquisition will be challenging, since no autonomous sensors are present in FMCG factories yet and data is still mostly manually collected. Moreover, the consolidation of data in a centralised place appears to be challenging, since currently, data is still stored decentralised. Also, there is little standardisation in the data acquisition, because of the little standardisation in manufacturing systems (Uhlemann et al., 2017). The uncertainties around data acquisition are challenging: how to collect and what to collect.

The smart manufacturing concept is challenging to implement, because fully self-organised, i.e. autonomous, manufacturing systems are not mature yet (Wang et al., 2016).

The modularised concept of a FMCG factory is still challenging, because there are no simply applicable design requirements that can be used related to the manufacturing system and the facility (Hermann et al., 2016).

9.3 Future Process

This paragraph describes the design of the future process of construction projects in the FMCG manufacturing industry. The paragraph is divided into four sub paragraphs, according to the different themes of the sub research questions. The first paragraph describes the phases and durations of the future process (Paragraph 9.3.1). The second paragraph describes the project organisation in the future process (Paragraph 0). The third paragraph describes the information management in the future process (Paragraph 9.3.3) and in the fourth paragraph the challenges of the future process are described (Paragraph 9.3.4). In appendix H (Figure H-1), the synthesis of the future process of construction projects in the FMCG manufacturing industry can be found.

9.3.1 Future Phases and Durations

In the design of the future process of construction projects in the FMCG manufacturing industry (Appendix H; Figure H-1), the duration of each phase is specific for construction projects in the FMCG manufacturing industry. The initiation phase happens continuously, the duration of the design phase differs per project, construction can be done in less than a year and the factory is monitored for 1 year in the exploitation and maintenance phase. The new duration of each phase is described related to the implementation of the Industry 4.0 technologies.

Currently, the adoption of artificial intelligence solutions is low in construction projects. However, the implementation of artificial intelligence in the construction industry offers possibilities throughout all project phases (Blanco, Fuchs, Parsons, & Ribeirinho, 2018):

- In the initiation phase by project planning optimisation and predictive forecasting of project risks
- In the design phase by predictive testing of materials
- In the construction phase by product and materials supply chain optimisation, 3D printing for prefabricating of products and materials, and robotics for on-site assembling of products and materials

In the initiation phase, happening continuously, the use of big data acquisition and analytics and virtual reality can solve the current problems of these phases. The real-time data acquisition of the demand of the FMCG value chain can assure the validity of the business case constantly. The use of digital real-time data and analytics can be used throughout all stages of the lifecycle of the factory. FMCG factories are part of supply- and demand-chain, for which the use of big data acquisition and analytics is of higher importance than for other built objects (Oesterreich & Teuteberg, 2016). Moreover, the use of virtual reality of concept designs in the initiation phase already, are expected to help for the realistic establishment of the project schedule and the project budget.

The design phase of the project, which is expected to be less than a year in the future situation, can become more time and cost-efficient by using 5D BIM models, parametric design and linked data analytics technologies (King, 2017).

The use of additive manufacturing techniques and advanced robotics can be used during the construction phase of the project, by 3D printing construction materials and assembling the materials on site with the help of robotics. Moreover, the time-consuming surveillance during the construction phase can become less time-consuming for people, by the use of advanced robotics technologies, such as drones for surveillance (Oesterreich & Teuteberg, 2016).

For the construction projects in the FMCG manufacturing industry, the changeability of the whole process of the construction project and the time-efficient process approach are important. Therefore, the application of Industry 4.0 technologies focuses on enhancing these project drivers.

9.3.2 Future Project Organisation

Related to the future project organisation of construction projects in the FMCG manufacturing industry both horizontal and vertical integration could help to enhance the opportunities of Industry 4.0

The horizontal integration means at least the integration of the main actors in the process (Oesterreich & Teuteberg, 2016): the FMCG manufacturer, the service supplier, the process product supplier and the civil product supplier. The vertical integration of the different disciplines (i.e. departments) is specifically important in construction projects in the FCMG manufacturing industry, since these disciplines can have different and sometimes even opposing stakes (Case study interview, 27th of June 2018).

The number of actors and stakeholders involved in construction projects is generally big, which makes the project organisation generally complex (Lester, 2007). With the emerge of Industry 4.0 trends, the development of a so-called eco-system of actors around the FMCG manufacturer is needed to be able to deliver project successfully (Fry et al., 2017). Industry 4.0 technologies, such as digital multi-dimensional BIM models and other virtual reality techniques can and will enhance the development of an ecosystem of actors, collaborating together on the same model (Davies & Sendler, 2018b).

9.3.3 Future Information Management

For construction projects in the FMCG manufacturing industry, information management is specifically important, because of the iterative character of the process phases (Case study interview, 27th of June 2018). The continuously iterative process (i.e. the continuous feedback loop) is supported by a constant flow of real-time information (Oesterreich & Teuteberg, 2016).

Collaboration and knowledge sharing is of particular importance in large scale construction projects with big project complexity (Bektas et al., 2013). In the future situation in the context of Industry 4.0, collaboration is said to be even more important, as stated by Fry et a. (2017, p. 9). This is caused by the of the increasing importance of changeability and integration (Paragraph 9.1.2) (Davies & Sendler, 2018b; Wang et al., 2016; Zhou & Liu, 2016).

"Collaboration is vital to successfully build competitive advantage and realise the opportunities from Industry 4.0" (Fry et al., 2017, p. 9)

Related to information management, Industry 4.0 has the power to bridge geographical distances (Dallasega et al., 2018). The complex project organisational structures of construction projects in the FMCG manufacturing industry, often subdivided into global and local organisations, without physical proximity to the project site (Dallasega et al., 2018), ask for an advanced central data environment to store, share and collaborate with preferably real-time information. Related to the central data environment is the importance of cybersecurity. The confidentiality of project information is important in the FMCG industry, because of the fierce competitiveness (Aconex & Boston Consulting Group, 2017).

9.3.4 Benefits and Challenges

The future process of construction projects in the FMCG manufacturing industry has certain benefits when compared to the current situation of the process (Paragraph 7.3). However, since the trends, technologies and concepts related to Industry 4.0 are rather new, there are also possible challenges implementing these in the process of construction projects in the FMCG manufacturing industry.

Benefits

Related to the traditional project drivers and the project control aspects of organisation and information (Figure 1-7), among the benefits of implementing Industry 4.0 practices in the process of construction projects in the FMCG manufacturing industry, the following can be found (Oesterreich & Teuteberg, 2016):

- Time and cost savings and on-time and on-budget delivery
- Improving quality
- Improving collaboration, documentation and communication

Time can be saved by using innovative manufacturing technologies, such as prefabrication or additive manufacturing, for producing the construction supplies. Moreover, BIM can be used, helping to decrease the delivery time (Oesterreich & Teuteberg, 2016). Cost can be saved through the automation of labour-intensive processes and the reduction of material cost, by using the innovative techniques described above and advanced tracking methods. Also, BIM can help controlling the budget (Oesterreich & Teuteberg, 2016). Quality can be improved by overcoming errors by the use of BIM. Moreover, big data analytics can be used to make well-substantiated decisions based on historical data (e.g. lessons learned) (Oesterreich & Teuteberg, 2016). Organisational and information management can be improved by the use of innovative collaboration, documentation and communication platforms, e.g. cloud, BIM-based platforms, social media apps, real-time tracking systems, etc. (Oesterreich & Teuteberg, 2016).

Challenges

As stated by Oesterreich and Teuteberg (2016, p. 122): *"Companies from construction industry not managed to integrate Industry 4.0 technologies yet."*. By reflecting on the traditional project drivers, the project control aspects of organisation and information and the additional project drivers, challenges for the integration of Industry 4.0 technologies in the construction industry are identified as:

- High implementation cost
- Organisational and process changes
- Knowledge management and enhancement of existing communication networks
- Lack of standards

The construction industry needs incentives for implementing technologies with high implementation costs. If the benefits are not clear, the implementation will be very challenging to realise (Oesterreich & Teuteberg, 2016). Moreover, for the implementation to be successful, it must take place at all levels of the organisation, which could lead to organisational and process changes (Oesterreich & Teuteberg, 2016). The construction industry is characterised by limited standards for knowledge management, due to the temporary nature of projects and the fragmented value chain. This makes the implementation of collaboration, documentation and communication systems challenging (Oesterreich & Teuteberg, 2016). Although the maturity level of certain Industry 4.0 technologies is already quite high, the standards for implementing them in dynamic environments are still lacking (Oesterreich & Teuteberg, 2016). The unique and tailored nature of construction projects make it more challenging to implement certain Industry 4.0 technologies, because of the lack of standards. The benefits of technologies such as prefabrication, automation and robotics can only be enhanced when the processes of construction projects become more repetitive, like manufacturing processes (Aconex & Boston Consulting Group, 2017).

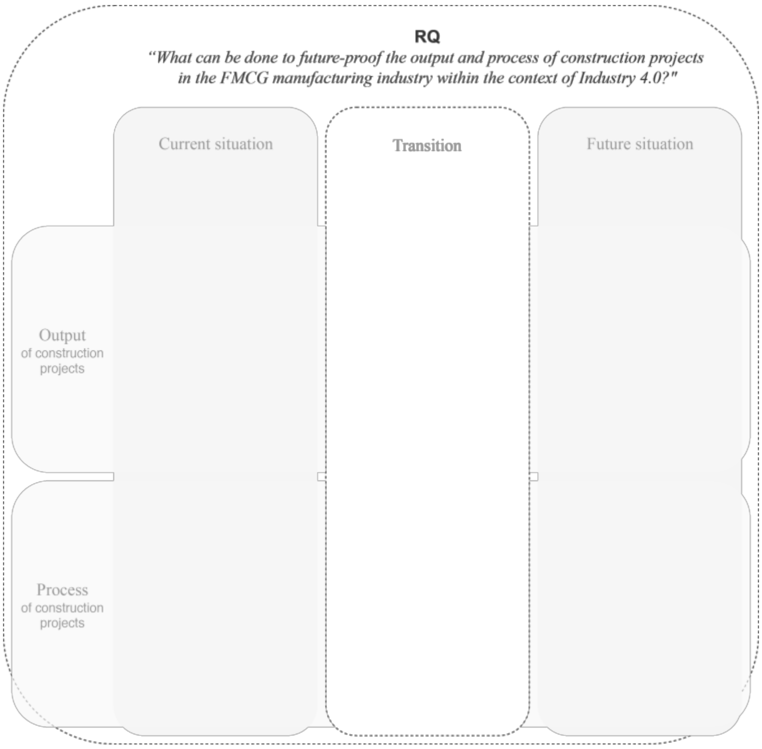
Certain specific characteristics of the construction industry are identified as obstacles for the implementation of Industry 4.0 technology in its processes. Firstly, the construction industry is characterised as *"rigid and resistant to changes"* (Paragraph 1.1.3) and its projects are known for their inability to adapt (Oesterreich & Teuteberg, 2016). Secondly, the processes are characterised as complex, because of the high number of interrelated processes and sub-processes and participating actors at different stages and locations. Thirdly, the high degree of customisation and the uncertainties caused by the on-site conditions are identified as hampering factors. Fourthly, the lack of innovation in the construction industry is hindered by the industries' complexity (Jensen, 2017, p. 872).

"The construction industry is repeatedly found to have low rates of innovation than other industries." (Jensen, 2017, p. 872)

10

Design Transition Roadmap from Current to Future Situation

This chapter presents the design of the transition roadmap from the current to the future situation of construction projects in the FMCG manufacturing industry.



Trends influencing the FMCG manufacturing industry (Paragraph 8.1), result into challenges as a result of these trends (Paragraph 8.2). Opportunities of the Industry 4.0 (Paragraph 8.3) result into a transition from the current (Chapter 7) to the future situation (Chapter 9) of construction projects in the FMCG manufacturing industry.

Transition roadmap criteria (Paragraph 8.4.1) and a concept design (Paragraph 8.4.2) are established. These are taken into account for the design of the transition roadmap, presented in this chapter.

The transition roadmap in combination with the design of the future situation (Chapter 9), can be used by the actionable actors (i.e. the FMCG manufacturer, the service supplier and the process product supplier) to future-proof the construction projects in the FMCG manufacturing industry (Küper et al., 2013). The transition roadmap aims to do so by enhancing the opportunities of Industry 4.0. Since the opportunities in the context of Industry 4.0 are continuously developing, it is recommended to use the roadmap iteratively and continuously review the steps taken and potentially change certain steps.

The overview of the three-actor-dimensional transition is provided (**Error! Reference source not found.**) and further explanation on the background of the steps is given.

The importance of the involvement of change agents in the company that feel ownership over the change related to the Industry 4.0 strategy, is stressed by (Oesterreich & Teuteberg, 2016). Moreover, the human capabilities defined are retrieved from findings from the exploratory interviews. The digital skills are a minimum capability for all actors in construction project in the FMCG manufacturing industry (Aconex & Boston Consulting Group, 2017). Since generally the capabilities of service suppliers in the construction industry regarding digitisation are underdeveloped (Oesterreich & Teuteberg, 2016), they are recommended to focus on enhancing digitisation first.

All steps related to the focus on Industry 4.0 trends and technologies are based on the literature review on these (Paragraph 8.3). The five steps (step 4 - step 8), related to project drivers, organisation and information, are based on the design of the future situation of construction projects in the FMCG manufacturing industry (Chapter 9). Finally, the reviewing and redefining part of the transition roadmap is based on the continuously developing context of Industry 4.0 (Hoda et al., 2008).

	Transition steps FMCG manufacturer	Transition steps Service supplier *In construction projects in FMCG manufacturing industry*	Transition steps Process product supplier *In construction projects in FMCG manufacturing industry*
1	• Focus on Industry 4.0 trend: data acquisition, computational power and connectivity • Focus on Industry 4.0 technologies enabling big data acquisition • Start collecting big data on consumer's demand	• Focus on trend: digitalisation (instead of focusing on other more complex technologies) • Start with the digitisation of services: design, engineering, planning, budgeting, etc.	• Focus on Industry 4.0 trend: advanced conversion to physical world • Start with exploring the possibilities of smart manufacturing
2	• Define company's specific Industry 4.0 strategy • Involve change agents in the company that feel ownership over the change related to the strategy		Define and invest in the human capabilities needed to implement the company's specific Industry 4.0 strategy: • Digital skills • Continuous learning • Problem-solving • Collaborative • Communicative • Agility and proactive
3	• Focus on Industry 4.0 technologies enabling big data analytics and intelligence • Start analysing big data on consumer's FMCG demand to be able to predict	• Focus on Industry 4.0 trend: advanced human-machine interaction • Focus on Industry 4.0 technologies enabling advanced design methodologies • Start using 5D BIM (3D, incl. planning, budget)	• Focus on Industry 4.0 advanced robotics technologies • Start developing the smart robotic technologies of autonomous and collaborative robots
4	Focus on and implement the additional project driver changeability in the process and output of construction projects in the FMCG manufacturing industry		Focus on and implement the additional project driver integration in the process and output of construction projects in the FMCG manufacturing industry
5	Start with developing changeable business cases (describing the business opportunity) by the use of big data acquisition and analytics on the consumer's FMCG demand	Start with developing changeable design and engineering processes by the use of 5D BIM in combination with parametric design	Start with developing changeable manufacturing technologies, such as additive manufacturing, i.e. 3D printing, in combination with advanced robotics technologies
6	Redefine organisational processes, such as work flows, team compositions, team dynamics, etc.		Redefine the system of reviewing, quality controls, etc. based on the continuously developing internal and external environment
7	Build a network of service suppliers, process product suppliers and civil product suppliers for construction projects in the FMCG manufacturing industry	Build an eco-system of global and local service suppliers around FMCG manufacturers for construction projects in the FMCG manufacturing industry	Build an eco-system of process product suppliers around FMCG manufacturers for construction projects in the FMCG manufacturing industry
8	Focus on standardised cloud-based documentation and realise a centralised real-time information management system		Focus on standardised effective communication strategies within and outside the company
9	• Review the development of changeable design and engineering processes by the use of the new technologies • Redefine Industry 4.0 strategy based on review	• Review the development of changeable design and engineering processes by the use of the new technologies • Redefine Industry 4.0 strategy based on review	• Review the development of changeable manufacturing technologies by the use of the new technologies • Redefine Industry 4.0 strategy based on review
10	Co-create a coherent Industry 4.0 strategy, based on learnings from the previous steps of each actor, to enhance the opportunities of Industry 4.0 in construction projects in the FMCG manufacturing industry		

	Different actions, to be taken by each actor separately
	Same actions, to be taken by each actor separately
	Same action, to be taken together by the three actors

Table 10-1 - Design transition roadmap from current - Future-proof construction projects in the FMCG manufacturing industry (Breunig et al., 2016; Hook et al., 2016; Rüßmann et al., 2015)

11

Validation

This chapter presents the validation of the designs. The chapter is divided into two paragraphs, according to the two validation steps. The first paragraph presents the design and result of the validation by the focus group (Paragraph 11.1) and in the second paragraph the design and result of the validation by the questionnaire is presented (Paragraph 11.2).

11.1 Validation Focus Group

Since the design of the validation focus group was only made after the data collection was done, the design will shortly be described before identifying the results of the validation focus group.

Design validation focus group

In appendix I (Table I-1), the attendees of the validation focus group can be found. From the service supplier perspective, two experts and two young professionals, all with background knowledge of a specific part of the FMCG manufacturing industry were asked for the focus group. The aim of combining experts and you professionals was to come up with creative ideas for the future situation, mostly by the young professionals, and directly test the underlying assumptions by the judgement of the experts. In appendix J (Figure J-1), the framework of the validation focus group can be found. The 3D-matrix is the basis for trying to establish relationships between the Industry 4.0 technologies, the factory components and the spatial requirements for the factory.

Results focus group

In appendix I (Figure I-2; Table I-2), the result of the validation focus group can be found. The described relationships are based on judgement of the focus group. The 3D-matrix could not be finalised during the focus group session and was finalised afterwards without the presence of the experts. Therefore, the results of the focus group cannot be seen as conclusive.

11.2 Validation Questionnaire

Since the design of the validation questionnaire was only made after the data collection was done, the design will shortly be described before identifying the results of the validation questionnaire

Design validation questionnaire

Since data analysis and results are based on the observations from multiple perspectives, both from the FMCG manufacturer perspective and from the service supplier perspective respondents for the validation questionnaire were asked. In appendix J (Table J-1), the design of the validation questionnaire can be found. The validation questionnaire was subdivided into parts related to the subdivision of the conclusions of the research. The questionnaire consisted of a mix of multiple-choice questions, in which it was often possible to choose multiple answers, and open questions. The multiple-choice questions were used to test the conclusions and the open questions were used to test the completeness of the conclusions.

Result questionnaire

In appendix J (Table J-2), the result of the validation questionnaire can be found. The questionnaire was filled-in by people recognized as experts in their professional field. Therefore, the results of the questionnaire can be seen as conclusive and is processed in the conclusion (Chapter 12).

Result

(Picture Royal HaskoningDHV, case study project 3 in Nigeria)

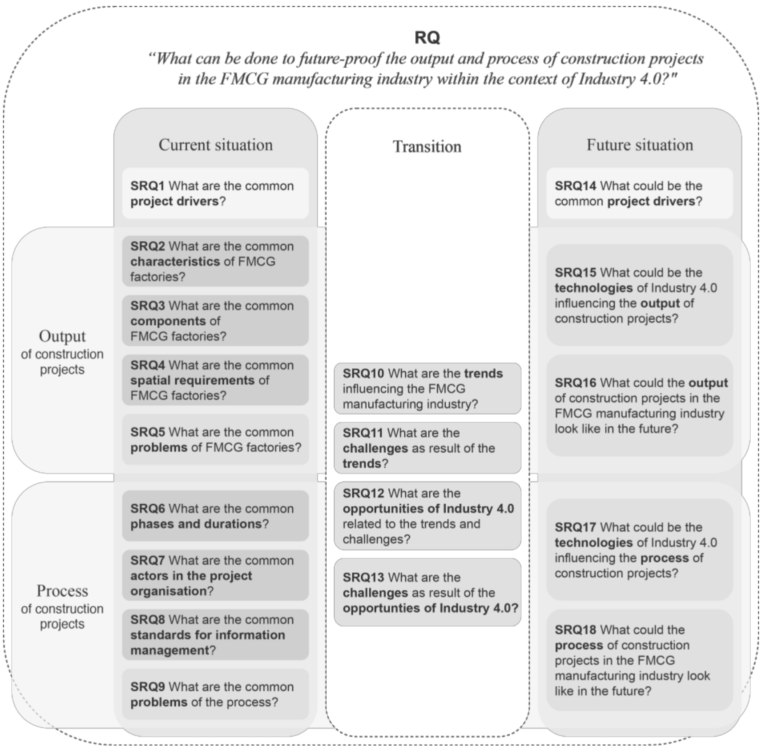
Result

The fifth and last part of this thesis, presents the result of the research, in three chapters. The first chapter presents the conclusion (Chapter 12). The second chapter describes the discussion of the research (Chapter 13) and in the third chapter the recommendations are presented (Chapter 14).

Research Context | Research Design | Data Collection | Data Analysis | **Result**

12
Conclusion

This chapter presents the conclusion by answering the sub research questions first and subsequently answering the main research question. The chapter is divided into four paragraphs, according to the different parts of the research. The first paragraph presents the answers to the sub research questions related to the current situation (Paragraph 12.1). The second paragraph presents the answers to the sub research questions related to the transition (Paragraph 12.2) and in the third paragraph the answers to the sub research questions related to the future situation are presented (Paragraph 12.3). In the fourth paragraph the answer to the main research question is presented (Paragraph 12.4).



12.1 Current situation

To answer the first nine sub research questions, information on the current situation (Chapter 7) is used. To answer the first sub research question (SRQ1), the characteristics of the FMCG market are linked to the FMCG manufacturing industry and the construction projects in the FMCG manufacturing industry.

> ***SRQ1*** *What are the common* ***project drivers*** *in construction projects in the FMCG manufacturing industry currently?*

Findings from the literature review indicate that the FMCG manufacturing industry is characterised as being part of a demanding value chain and a market with fierce competition. Moreover, the FMCG market is characterised by high delivery reliability, short delivery times, unpredictable demands and a great variety of goods. These characteristics are causing a higher pressure on the project drivers for construction projects in the FMCG manufacturing industry, compared to general construction projects.

Findings from the exploratory interviews conclude that higher pressure on the project drivers is generally imposed by the FMCG manufacturer, as the FMCG manufacturer aims to maximise its revenue. Time can be seen as equivalent for cost, since delays can directly be translated into revenue losses. Therefore, the FMCG manufacturer focuses most on time and least on quality.

Findings from the multiple-case study show that the pressure on the project drivers can differ per construction project. For example, due to different natures of projects: on projects with a secondary nature (i.e. related to the support of the manufacturing) the pressure on project drivers is higher than on projects with a primary nature (i.e. related to manufacturing volume). Another example that the pressure differs, is due to the different margins of goods produced: on projects with a low margin of goods the pressure on project drivers is higher than on projects with a high margin of goods. The differences in both examples are related to the intended revenue (i.e. as high as possible) of the FMCG manufacturer.

The main differences between project drivers in general construction projects and project drivers in construction projects in the FMCG manufacturing industry are the focus on time and generally the higher pressure on the project drivers.

To answer the second (SRQ2), third (SRQ3), and fourth (SRQ4) sub research question, the characteristics (Paragraph 7.2.1), components (Paragraph 7.2.2) and spatial requirements (Paragraph 7.2.3) of FMCG factories currently are linked to each other.

> ***SRQ2*** *What are the common* ***characteristics*** *of FMCG factories currently?*
> ***SRQ3*** *What are the common* ***components*** *of FMCG factories currently?*
> ***SRQ4*** *What are the common* ***spatial requirements*** *of FMCG factories currently?*

Findings from literature indicate that FMCG factories can be classified by three different characteristics: the good's type produced, the good's substance produced or the type of manufacturing process. The classification based on the good's type produced is generally most related to the spatial requirements of the FMCG factory, since this characteristic also defines the manufacturing process. FMCG factories can be subdivided into different levels to describe the components: components of the masterplans (i.e. buildings), components of the factories (i.e. building blocks) and components of the production units.

Findings from the multiple-case study show similarities between the components of the masterplans and factories of FMCG factories belonging to different classifications, based on the good's type. For all types of factories, the components of the factories are building blocks related to the flow of goods through the factories. Moreover, the building block dedicated to the utility unit (not part of the flow) integrate the building blocks related to the flow mass. Building blocks can be divided into production units. The combination of production units and the specific production units differ for each type of good.

Since similarities between the components of different classifications of FMCG factories can be found, a high standardisation of spatial requirements is expected. Moreover, this expectation is confirmed by findings from the literature review. For example, because FMCG factories are characterised by bulk manufacturing instead of smaller scale manufacturing in other types of factories. However, findings from the multiple-case study indicate that the spatial requirements for FMCG factories do not have the high rate of standardisation expected. The conflicting interests of different stakeholders in the FMCG manufacturer's project organisation often hamper the standardisation of FMCG factories, since the operational companies of the factories desire specific requirements for individual factories.

To answer the fifth sub research question (SRQ5), the characteristics of the FMCG market are linked to the FMCG manufacturing industry and the output of construction projects in the FMCG manufacturing industry.

SRQ5 *What are the common* ***problems*** *of FMCG factories currently?*

Practical experience shows that the overarching problem of the output of construction projects in the FMCG manufacturing industry is not being able to manufacturer the specification, volume, moment and location of the demand of the FMCG value chain. Findings from literature indicate this problem is caused by the contradictions between market requirements and manufacturing wishes and the complexity of the design, engineering and construction (i.e. the process of the construction project) of the FMCG factory.

The market requirement of a high delivery reliability of FMCG factories is challenging because of the long lead times and high initial costs in the first phase in the process of construction projects in the FMCG manufacturing industry. Moreover, the short delivery time of goods is required, which causes a low controllability of the manufacturing processes in the FMCG factories. Finally, the specificity of the market requirements (e.g. consumer demands) results in a great variety of end products and a risk of obsolescence of goods for FMCG factories. Moreover, findings from the exploratory interviews and the multiple-case study show, the problem is caused by limited changeability of and limited integration in FMCG factories.

In literature, changeability is defined as *"the ability of a system or facility to adjust to changes in its internal or external environment"* (Das & Patel, 2002, p. 266). Logically, changeability is constrained by the physical characteristics of FMCG factories. Moreover, changeability is related to the components of manufacturing environments and the specification level of goods.

Literature states that three types of integration should be realised in manufacturing industries to cope with manufacturing challenges: horizontal integration (i.e. integration of different actors within the value chain), vertical integration (i.e. integration of different disciplines within an actor) and end-to-end integration (i.e. integration of processes within the value chain). However, limited integration of each type is found in the FMCG manufacturing industry, based on findings from the exploratory interviews and the multiple-case study. Limited process-civil alignment and generally limited discipline alignment is found in the FMCG factories. This is expected to be caused by the complex character of the output construction projects in the FMCG manufacturing industry, the FMCG factory and by the complex character of the process of construction projects in the FMCG manufacturing industry (i.e. many different actors in project organisation without physical proximity).

To answer the sixth (SRQ6), seventh (SRQ7), and eighth (SRQ8) sub research question, the phases and durations, actors in the project organisation and standards for information management in construction projects in the FMCG manufacturing industry of FMCG factories are linked to each other.

SRQ6 *What are the common* ***phases and durations*** *in construction projects in the FMCG manufacturing industry currently?*
SRQ7 *What are the common* ***actors in the project organisation*** *in construction projects in the FMCG manufacturing industry currently?*
SRQ8 *What are the common* ***standards for information management*** *in construction projects in the FMCG manufacturing industry currently?*

Findings from literature show four common phases for general construction projects: initiation, design, construction and exploitation and maintenance). However, the multiple case study shows that in the process of construction projects in the FMCG manufacturing industry, the project can be put on hold during or after each phase, due to the continuous feedback loop to the business case. Business cases in the FMCG manufacturing industry continuously change because the business opportunities of the FMCG manufacturer continuously change due to changes in the external environment (e.g. changing market demand, changing competition, etc.). This does not only result into delays, moreover, this results into unfinished projects with sometimes unfinished construction sites.

From the multiple case-study is found that once the project budget is committed, after the initiation phase, the FMCG manufacturer wants the project to be finished as soon as possible so that the FMCG factory can generate revenue. The duration of the design phase is around half a year and the construction phase around 1 year (if the project is not put on hold). However, different actors in the project organisation have different and sometimes even opposing perspectives. For example, the global division of a FMCG manufacturer focusses mostly on the revenue, whilst the operational company of the factory focuses mostly on a workable manufacturing environment.

The differences between perspectives of different actors in the project organisation make the process of general construction projects complex. In the multiple-case study it is observed that the project organisations of construction projects in the FMCG manufacturing industry can be characterised as being even more complex. This is due to the very specific kind of knowledge that is needed for the different disciplines of a factory: for example, packaging process engineering, filling process engineering, etc. These different disciplines are all found working on their own specialism “island”, whilst there is a need for more inter-disciplinary approach.

Due to the little cognitive proximity (i.e. actors do not have all knowledge related project) and the little physical proximity (i.e. big distance from construction site) of actors in construction projects in the FMCG manufacturing industry, information management is important. Otherwise poor knowledge sharing can result into problems in the process.

To answer the ninth sub research question (SRQ9), the characteristics of the FMCG market are linked to the FMCG manufacturing industry and the process of construction projects in the FMCG manufacturing industry.

SRQ9 *What are the common* ***problems*** *of the process of construction projects in the FMCG manufacturing industry currently?*

Practical experience shows that the overarching problem of the process of construction projects in the FMCG manufacturing industry is defined as a poor project process in the perspective of one or more actors in the project organisation. This problem can be caused by different problems related to the project drivers (i.e. time, cost and quality, within a fixed scope), the other two project control aspects (i.e. organisation and information) and limited changeability and limited integration.

An unrealistic planning of schedule and budget is typical for the FMCG manufacturing industry, due to the continuous feedback loop to the business case. Moreover, from the multiple-case study it is found that the organisational problems are partly caused by the international character of the projects (i.e. cultural differences) and partly caused by the specific opposing stakes of actors in the FMCG manufacturing industry. Limited changeability is caused by the static formulation of the business case, whilst the demands of the FMCG value chain are characterised as volatile. Although the disciplines of process and civil are highly interdependent in the process of construction projects in the FMCG manufacturing industry, little integration between the two disciplines is found.

12.2 Transition

To answer the next four sub research questions, information on the transition (Chapter 8) is used. All information is derived from the literature review. Trends causing challenges and opportunities of Industry 4.0 causing new challenges, are linked to each other.

To answer the tenth (SRQ10) and eleventh (SRQ11) sub research questions the mega trends, identified by the PESTE analysis (Paragraph 8.1), are linked to consumer and manufacturing demands, to identify the challenges for the FMCG manufacturing industry (Paragraph 8.2).

> ***SRQ10*** *What are the* ***trends*** *influencing the FMCG manufacturing industry?*
> ***SRQ11*** *What are the* ***challenges*** *as the result of the* ***trends****?*

Several trends in the categories of political, economic, social-cultural, technological and environmental (i.e. PESTE) are influencing consumer demands and therefore also manufacturing demands. Individual consumer demands for FMCG are digitalising, individualising and in need of immediate fulfilment. Fierce global competitiveness, a big pressure on time, cost and quality, an increasing demand for changeability and integration, are found to be the manufacturing challenges for the FMCG manufacturing industry related to these changing demands. These manufacturing challenges also result into challenges for the construction projects of these factories.

To answer the twelfth (SRQ12) and thirteenth (SRQ13) sub research questions, the opportunities of Industry 4.0 are identified and defined (Paragraph 8.3) and furthermore, linked to the challenge of a transition caused by the opportunities (Paragraph 8.4).

> ***SRQ12*** *What are the* ***opportunities of Industry 4.0*** *related to the trends and challenges influencing the FMCG manufacturing industry?*
> ***SRQ13*** *What are the* ***challenges*** *as the result of the* ***opportunities of Industry 4.0****?*

The opportunities of data acquisition and analytics, advanced conversion to the physical world and advanced human machine interactions can be enhanced by the implementation of different Industry 4.0 technologies and design concepts for the FMCG factory of the future. These four trends are linked to specific Industry 4.0 technologies These opportunities can help overcoming the manufacturing challenges in the FMCG manufacturing industry. However, the opportunities of Industry 4.0, could result into a transition and therefore into possible new challenges. To cope with the challenges of a transition, a strategic vision of the future and a transition roadmap, in which actors commit to short-term actions, can be used.

12.3 Future situation

To answer the next four sub research questions, information on the future situation (Chapter 9) is used. To answer the fourteenth sub research question (SRQ14) the pressure on current project drivers and the introduction of additional project drivers are considered.

SRQ14 *What could be the common **project drivers** in construction projects in the FMCG manufacturing industry in the future?*

Implementing Industry 4.0 technologies in construction projects in the FMCG manufacturing industry can help to meet the pressure related to the traditional project drivers of time, cost, quality and fixed scope, by increasing the efficiency in the projects. Moreover, changeability and integration are identified as additional project drivers. Integration to align the different specialist disciplines, to eventually stimulate changeability. Changeability to remain competitive while the demand on the FMCG factory is continuously changing and so that the construction process can deal with the continuous feedback loop to the business case. The FMCG manufacturing industry, more than other types of industry, is characterised by the combination of highly complex interacting manufacturing systems internally and continuously changing demands externally.

SRQ15 *What could be the **technologies** of Industry 4.0 influencing the **output** of construction projects in the FMCG manufacturing industry?*

SRQ16 *What could the **output** of construction projects in the FMCG manufacturing industry look like in the future?*

The three concepts of cyber-physical manufacturing, smart manufacturing and modular manufacturing are the starting point for the future design of the output of construction projects in the FMCG manufacturing industry, the FMCG factories. The FMCG factory of the future is characterised by integrated cyber-physical systems, smart autonomous manufacturing steering and advanced analytics and interconnectedness of all systems in the factory.

The components of the FMCG factory of the future are similar to the current FMCG factory. However, the dimensions of the components will be different in the future situation, since the cyber-physical and smart systems will influence these dimensions and in combination with modular set-ups will enable decentralised manufacturing systems. Regarding the spatial requirements, FMCG factories are expected to need less surface (m^2), due to the decreasing good's stock and the decreasing number of people working in the factory. However, designing with tolerances related to the area could increase the changeability of the FMCG factory.

SRQ17 *What could be the **technologies** of Industry 4.0 influencing the **process** of construction projects in the FMCG manufacturing industry?*

SRQ18 *What could the **process** of construction projects in the FMCG manufacturing industry look like in the future?*

The future process of construction projects in the FMCG manufacturing industry will be characterised by the same process phases. With the focus on changeability and integration as additional project drivers, the durations of the phases are expected to change. The focus on changeability will enhance the continuous feedback loop to the business case during the process. The opportunities of Industry 4.0, related to the organisation of and information exchange between actors, can be enhanced with the focus on end-to-end and horizontal integration.

The real-time data acquisition of the demand of the FMCG value chain can assure the validity of the business case constantly, by applying big data analytics. Moreover, the information from the data analytics, in combination with a parametric design model, are expected to make the design phase more time- and cost-efficient. The use of additive manufacturing for the construction products and the use of advanced robotics for the assembly of these products on site are expected to decrease the duration of the construction phase.

12.4 Transition Roadmap from Current to Future Situation

To answer the main research question (RQ), all information on the current situation (Chapter 7) and the transition (Chapter 8), is used to construct a transition roadmap. Together with the design of the future situation (Chapter 9), the transition roadmap aims to guide the transition from the current to the future situation of construction projects in the FMCG manufacturing industry. The three main and actionable actors are considered in the transition roadmap: the FMCG manufacturer, the service supplier and the product supplier.

Research Question (RQ)
What can be done to future-proof the output and process of construction projects in the FMCG manufacturing industry within the context of Industry 4.0?

All actors are recommended to focus on specific Industry 4.0 trends and technologies. Moreover, by implementing changeability and integration as additional project drivers, all actors can start developing changeable and integrated parts of their services and products.

The FMCG manufacturers could focus on the data acquisition and analytics of the consumer's demand, to develop a changeable business case. Since generally the capabilities of service suppliers in the construction industry regarding digitisation are underdeveloped, they could focus on enhancing digitisation first. To eventually start developing changeable design and engineering processes by the use of 5D BIM in combination with parametric design. The process product suppliers could focus on the Industry 4.0 technologies related to advanced conversion to the physical world, such as smart robotic technologies and additive manufacturing.

The realisation of an eco-system of service suppliers and process product suppliers around the construction project of a FMCG manufacturer, in combination with standardised cloud-based documentation and standardised communication strategies, could then be the next step towards future-proof construction projects in the FMCG manufacturing industry. Since the context of Industry 4.0 is continuously changing, the review of developments and the redefinition of the Industry 4.0 strategy, based on these reviews, is recommended to all actors.

Based on their learnings by developing and reviewing their changeable systems by the use of Industry 4.0 technologies, the FMCG manufacturer, service supplier and process product supplier could co-create a coherent Industry 4.0 strategy. By the use of this strategy in combination with the design of the future situation of construction projects in the FMCG manufacturing industry, the output and process of construction projects in the FMCG manufacturing industry are more future-proof.

13

Discussion

This chapter describes the discussion of the research. The chapter is divided into five paragraphs, according to the different parts if this thesis. The first paragraph describes the limitations of the research context (Paragraph 13.1). The second paragraph describes the limitations of the research design (Paragraph 13.2). The third paragraph describes the limitations of the data collection (Paragraph 13.3) and in the fourth paragraph the limitations of the data analysis and results are described (Paragraph 13.4). In the fifth paragraph the scientific and practical contribution of the research is discussed (Paragraph 13.5).

13.1 Limitations of Research Context

In the research context, the gap between the current and future situation was defined as a problem (Paragraph 2.1.1). Analysing a gap between a current and a future situation is mostly practice-oriented, since it is trying to solve the problem of the gap (Verschuren & Doorewaard, 2013). However, scientific research is not a necessarily a problem-solving method, but research is used to create knowledge.

The limitation of the practice-oriented problem definition was tried to resolve by conducting an exploratory research. With the exploratory nature of this research it was not aimed to directly solve the problem of the gap between the current and future situation. It was rather aimed at giving insights and information related to the problem (Verschuren & Doorewaard, 2013).

13.2 Limitations of Research Design

The limitations of the research design are related to the selected data collection methods, the selected data analysis methods and the validation design of the research.

Limitations data collection design

Verschuren and Doorewaard (2013) provide two case study project selection strategies: choosing either projects with a maximum or a minimum number of differences. For this research five case study projects of multinational FMCG manufacturers were selected, which represents one of the similarities of the projects. However, the projects did also differ from each other by for example, differentiation in green- and brownfield projects, the location, etc. To resolve the limitation of not having a maximum or a minimum number of differences, the design of the project documentation analysis and the case study interviews was made very carefully, to be still able to compare the different case study projects. Future research is recommended to focus on for example projects with a maximum amount of similarities, such as only greenfield projects, projects producing a specific type of FMCG (e.g. all household care), etc.

The selection of interviewees for both the exploratory interviews and case study interviews was done on the basis of person's perspective, company, function, role and experience, which made the interviewed interviewees relevant, but does not mean *all* relevant interviewees were being interviewed. To resolve this possible limitation, all interviewees were asked who else would we relevant to interview.

The actual designs of the exploratory and the case study interviews also have their limitations. The exploratory interviews were held without interview guide. From these interviews can therefore be concluded which concepts were of importance for the interviewee. However, this does not mean the concepts that were not discussed were of no or little importance for the interviewee. On the other hand, the interview guide of the case study interviews could be a limitation for the case study interviews, because the bias of the researcher is probably incorporated into the interview guide. It was tried to resolve these two limitations, by taking enough time for each interview. Therefore, it was tried to encourage the interviewee to also come up with possible relevant subjects.

Limitations data analysis design

The limitations of the data analysis design are mostly due the to the exploratory nature of this research. Since the data collection consists of many opinions instead of factual knowledge, the bias of the researcher is a limitation when analysing the data. It is tried to mitigate this by an extra validation design.

Limitations validation design

Although precautions have been in the validity of the data collection and to validate the data analysis, the validity of the data is hard to ensure. For example, the closed questions in the validation questionnaire may bias the respondent (Verschuren & Doorewaard, 2013). However, it is tried to mitigate this limitation by also providing room for optional extra explanations.

13.3 Limitations of Data Collection

The common limitations of the exploratory interviews (Paragraph 3.3) and the multiple-case study (Paragraph 4.3) are described in the design part of both methods. In this paragraph the limitation of data collection in general will described.

Defining and operationalising

The concepts used for data collection were defined and operationalised in the first phase of the research. The defining and operationalising of the concepts was mostly done based on the first data collected through the exploratory interviews and the multiple-case study, due to the limited availability of literature. Therefore, most definitions and indicators (i.e. for measuring the concepts) were derived from practice, instead of from theory. A recommendation for future research would be defining and operationalising the concepts based on theory instead of practice.

Missing knowledge

Finally, a limitation of the data collection is the risk of missing knowledge. Although a lot of information and knowledge has been collected, there has not been a systematic review of the completeness of the knowledge collected. This limitation is mitigated by validation in several steps.

13.4 Limitations of Data Analysis and Results

Since there are large differences between the construction industry and the manufacturing industry, the adaption of Industry 4.0 trends and technologies will have different efficiencies. Examples of key differences between the two industries are (McKinsey Global Institute, 2017):

- Construction sites are not mobile and cannot be moved to where labour is available
- Workspaces on construction sites overlap in the same areas and therefore, the planning of workflows is challenging
- Sites are dynamic - construction sites change continuously (in size and other aspects)
- Staging and setup is continuous in construction
- Different uncontrolled variables: weather conditions, site conditions
- Less heterogeneity in supplies for construction industry

The focus on both the manufacturing industry and construction projects during this research limits the data analysis and limits the practical applications and therefore, the research results. The combined knowledge fields and the exploratory nature of the research resulted into explorative conclusions, rather than conclusive evidence. This could have led to the generality, rather than specificity, of the conclusions. For future research it is therefore recommended to try to specific the knowledge field more, to be able to draw more specific conclusions.

Moreover, Ross et al. (2008) state that for designing for the future, the designs should not only meet current and future requirements, but also keep an eye on the further future by building in change mechanisms into the design to allow continuous changes. Moreover, implementing future designs (e.g. implementing Industry 4.0 technologies) bring new challenges. In the thesis, it is tried to stress the importance of being aware of the continuously changing environment and the new challenges possible implementations could bring.

13.5 Scientific and Practical Contribution

The scientific relevance (Paragraph 1.2.1) and the practical relevance (Paragraph 1.2.2), were described related to the research gap. This paragraph compares the goals defined in the research context to the eventual result.

The scientific relevance of this research was defined as contribution to knowledge on construction projects in the FMCG manufacturing industry within the context of Industry 4.0 (Paragraph 1.2.1). The scientific contribution of this research is three-fold. Firstly, this research contributes to the theoretical fields of construction projects in the manufacturing industry and in specifically the FMCG manufacturing industry, both fields which are quite undeveloped theoretically. Secondly, a contribution is made to the theory on FMCG factories. Although the findings are mainly based on practical experience, they do contribute, due to the little theory available in this specific field. Thirdly, the research contributes to the processes of construction projects of FMCG factories.

The practical relevance of this research was defined as exploring how the current output and process of construction projects in the FMCG industry are changing and what could be the opportunities of Industry 4.0 related to these changes (Paragraph 1.2.2). By the explorative designs of a future situation and a transition roadmap, based on the opportunities of Industry 4.0, this research contributes practically.

14

Recommendations

This chapter presents the recommendations of this research. The chapter is divided into two paragraphs. The first paragraph presents the recommendations for the actors in construction projects in the FMCG manufacturing industry (Paragraph 14.1) and in the second paragraph the recommendations for future research are presented (Paragraph 14.2).

14.1 Recommendations for Actors in Construction Projects in the FMCG Manufacturing Industry

Since the transition roadmap focusses on the three actionable actors related to the problem definition and the research objective, the recommendations for actors in construction projects in the FMCG manufacturing industry also focus on recommendations for these three actors: the FMCG manufacturer, the service supplier and the process product supplier.

Invest in human capabilities related to Industry 4.0

All actors are recommended to invest in human capabilities related to Industry 4.0. Currently, both processes in both the manufacturing and construction industry are still mainly steered by human brains. Before humans will fully be excluded from the steering and management of factory processes, it will be worth to invest in human capabilities (Ewenstein et al., 2015; Oesterreich & Teuteberg, 2016). The human capabilities related to Industry 4.0 can be seen in a broad sense, instead of only technological. The solutions of Industry 4.0 technologies will enable humans to focus on non-technological problems, such as cross-cultural management or collaborative design in engineering.

Invest in technology capabilities related to Industry 4.0 technologies

Industry 4.0 technologies are disrupting every industry (Zhou & Liu, 2016). To remain competitive, all actors are recommended to also invest in the technological capabilities related to Industry 4.0.

Invest in capabilities running the core business and enhance an external eco-system of service and product suppliers

For all actors, it is recommended to invest in the capabilities need for running their own core business, instead of losing focus by also investing in other types of capabilities. However, to fully enhance the opportunities of Industry 4.0 in construction projects in the FMCG manufacturing industry, all actors are recommended to closely collaborate. An eco-system of service and product suppliers around a FMCG manufacturer, together with a co-created Industry 4.0 vision could stimulate enhancing Industry 4.0 opportunities.

14.2 Recommendations for Future Research

Since this research is conducted within a certain scope and with certain limitations, recommendations for future research can be made.

Further validate results from this research

Since this research was conducted exploratory, further validating the results, by for example testing them, is recommended for future research.

Construction projects of other specific manufacturing industries

Although this research focuses on the specifics of the FMCG manufacturing industry, which is a big global industry, some general conclusions for the manufacturing industries could be drawn. However, other specific manufacturing industries will have different specific characteristics and therefore the implementation of Industry 4.0 technologies in these industries could require further research.

Construction projects in the FMCG manufacturing industry of a specific type of FMCG factory

For this research, all types of FMCG factories are taken into account. For future research it is recommended to research a specific type of FMCG factory, for example factories producing only beverages, or a packaged food. This future research direction could lead to more specific results and conclusions.

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Appendices