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a case study in Denmark

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Innovation opportunities from made-to-order gypsum boards in renovation projects: a case study in Denmark

Nussholz, Julia[1]; Toca Pérez, Cristina[2]; Salling, Stephanie[2]; Søgaard Jørgensen, Michael[1]; Wandahl, Søren[2]

[1]Aalborg University, Department of Planning, A. C. Meyers Vænge 15, 2450 København SV, Denmark
[2]Aarhus University, Department of Civil and Architectural Engineering, Inge Lehmanns Gade 10, 8000 Aarhus C, Denmark

jlkn@plan.aau.dk

Abstract. To reduce embodied emissions and waste in renovation projects, new resource efficient and low waste construction processes are needed. One possible solution to reduce waste at the construction can be made-to-order (MTO) customisation of standard products that are delivered in the right size and quantity. A key construction process in renovation projects is the installation of gypsum for partition wall construction. Today, gypsum boards are cut to the right size at the construction site, resulting in 15-30% of waste. In several countries, pilots for delivering MTO gypsum boards in the right length for the building dimension have shown significant potential to reduce waste and increase productivity. This study aims to help the material manufacturer Saint-Gobain Denmark explore innovation opportunities from MTO gypsum boards for the Danish market. Work sampling at a renovation project is conducted to identify the activities of the current installation process and potential time savings from MTO. Interviews are used to identify actors and their roles in the current value chain for partition wall construction in Denmark and possible scenarios to offer MTO. Results show that a rise in the production time from 31% to 36% could be achieved by avoiding measuring and cutting of boards at the construction side. Two value chain scenarios for delivering MTO in the Danish market are presented. Based on the results, potential drivers and barriers for MTO in the Danish market are discussed.

Keywords: resource efficiency; circular economy; business models; renovation; prefabrication

1. Introduction

The European Renovation Wave aims at renovating 35 million buildings until 2030 to reduce CO_2 emissions from the building stock by 55% [1]. In recent years, the materials and processes applied during the renovation phase have received increasing attention to reduce embodied emissions [2–6]. Next to environmental considerations, cost and time efficiency is a key consideration in the management of renovation projects [7] as for example promoted by the EU green deal that emphasises the importance of highly efficient construction processes to achieve as much green transition in the built environment as possible [8].

In Denmark, there is a strong policy focus on the renovation of existing buildings in the most cost-efficient way [9, 10]. Also waste reduction in the construction process is a stipulated policy goal in the national "Strategy for Sustainable Construction" [11]. The main activities conducted in typical renovation and retrofitting projects in Denmark consist of insulation of roof, facade, and floor; installation of high-efficiency windows (glazing and frames); improvement of heating system and mechanical ventilation with heat recovery. For this, most internal partition walls are demolished and rebuilt. The new lightweight partition and wall systems are mainly non-loadbearing, made up of, in most cases, a steel frame wall system with several layers of components, including insulation mats and gypsum boards. Installation of the gypsum boards on the steel frame represents one of the key construction processes in the retrofitting and renovation in Denmark.

Typically, 15-30% of gypsum boards delivered to the construction site is wasted in the installation [12]. The main reason for gypsum waste in the installation is the cut-offs from cutting boards to the right size at the construction site [13]. Cutting at the construction site is also time intensive and causes additional tasks, such as measuring boards and waste handling. One possible solution to reduce gypsum waste and installation time is the Made-To-Order (MTO) production of gypsum boards to the right size.

At Saint-Gobain, a multi-national company offering construction materials, MTO gypsum boards have been employed in different ways and with different levels of maturity in several countries for new build and renovation [14–16].

This research is part of a three-year transdisciplinary project conducted by Saint-Gobain Denmark to explore the potential value of MTO in the Danish market, including the drivers and barriers for scaling in the value chain [17]. As the first step in this process, this study aims to improve understanding of the gypsum installation process with and without MTO, including the potential productivity improvements from using MTO. Work sampling of a renovation project is used to identify the share of time spent on activities that could be avoided through MTO. Semi-structured and focus interviews with value chain partners and Saint-Gobain employees are used to map the current Danish value chain and identify two scenarios to offer MTO in the Danish market. Based on the results, drivers and barriers for each MTO scenario are discussed.

2. Literature Review

2.1. Made-to-Order as a sustainability opportunity

With increasing urgency to adopt more sustainable and resource efficient construction practices, the Lean Construction (LC) philosophy has received attention to deliver synergies with sustainability objectives [18]. LC aims at removing waste, increasing value, reducing costs, and improving the overall quality of products and processes [19]. Wandahl et al. [7] estimate that applying LC tools and methods can reduce waste and energy consumption in construction processes and thereby save 6.9 million tonnes CO2eq. from embodied emissions in Denmark (if applied to 35 million housing units). One way to reduce waste in the construction process can be MTO, where standard products are customised to the specific needs of customers [20, 21]. While MTO is not a designated method to reduce waste, customised production e.g., to the right size, can prevent waste from off-cuts at the construction site. While MTO has the potential to reduce waste and increase productivity [20], a disadvantage can be longer delivery cycles [20]. De Carvalho et al. [18] emphasise that there can also be trade-offs between sustainability goals and lean construction methods, such as MTO, if a lean construction process is not planned with sustainability aims in mind.

2.2. Experiences with Made-to-Order gypsum boards

MTO has been tested in construction projects in several of Saint-Gobain's country branches, both for new build and renovation. In the Benelux countries and France, MTO gypsum boards (both length and width) have been used in new build (Hotel Overamstel, Amsterdam) [14] and renovation projects (Hyatt

Hotel, Paris; Pullman Hotel, Montparnasse). In Sweden, Saint-Gobain tested the delivery of MTO gypsum boards and steel studs delivered in prefabricated packages, just-in-time and just-in-place for each room in the building (referred to as room packages) in the construction of two public buildings (e.g., Sigfridsborgs school and Okselvaegen preschool, Nacka) [15, 16]. Based on the evaluation by an external consultant [22] and measurements by Saint-Gobain employees, the Swedish case resulted in a waste reduction of 35% (compared with the contractors' estimate), productivity gains of 25% (construction time compared to planed hours), and customer satisfaction as the construction manager spent less time for overseeing the construction site) [15, 16].

3. Research Methodology

This research employs a multi-method approach combining: (1) work sampling technique in the case of a renovation project to explore potential time savings from MTO in gypsum installation and (2) interviews with value chain partners and Saint-Gobain employees to identify value chain scenarios for MTO.

3.1 Case study description

A case study is an empirical inquiry that investigates a contemporary *phenomenon* in depth and within its real-life context [23]. The *phenomenon* of this study is the process of installation of the gypsum boards that trained carpenters, hired by the contractor company, are executing. The renovation project consists of a non-residential building located in Ishøj, Denmark. The main renovation tasks are related to carpentry work, such as replacing windows, roofs, ceilings and creating new internal partition walls. The main activities of gypsum board installation were conducted inside the building, where also gypsum boards are stored. Pallets of boards were distributed throughout the building close to where they were used. Metal boxes with the tools used for the installation were stored inside the building close to the pallets of gypsum boards. Screws and dowels are used to attach the steel profiles to the partition walls.

3.2 Work Sampling description

In this study, the real-life context is represented by the construction site of the building under renovation The authors studied the installation of gypsum boards by applying the Work Sampling (WS) technique [24]. WS consists of a quantitative approach of intermittent, random, and instantaneous observations of activities of multiple workers by independent observers [24]. The theory of WS is based on the laws of probability, which indicate that observations taken at repeated random times will have the same distribution. Hence, random observations can be translated into percentages of time spent in work activities categories [24]. WS studies generally adopt the Ohno's [25] understanding of work as divided into Value-Added Work (VAW), understood as time spent in Direct Work (DW); and Non-Value-Added-Work (NVAW), understood as the time spent in Indirect Work (IW) and Waste Work (WW). Previous research [7] generally monitored construction operations using six-work activities categories. Two categories of DW: production and talking; two categories of IW: preparation; and transportation. Lastly, two categories of WW: walking and waiting. The WS procedure followed the following steps: (1) clarifying the work categories; (2) data collection; and (3) data analysis.

3.2.1 Step 1. Clarifying the work categories. The observers of the study, represented by the two first authors, developed a breakdown work classification of 32 activities related to the gypsum installation during the first day of the study. The adaptation of the WS Technique proposed by Salling et al. [26], called Breakdown Work Sampling (BWS), was adopted. BWS supports the easy identification of the time spent on each of the activities that compose one construction process by developing a detailed list of codes for each main work activity category. The adoption of a detailed list of codes allows, among other possibilities, to move codes from one main category to another. This represents a transparent way of manipulating the data that can be useful when comparing data to previous studies, where observations have been categorised differently [26], and to simulate different possible scenarios assuming other conditions. The breakdown codes were classified within six categories (see Appendix 1): (1) Production

(7 codes); (2) Talking (2 codes); (3) Preparation (11 codes); (4) Transportation (4 codes); (5) Walking (4 codes); and (6) Waiting (4 codes).

3.2.2 Step 2. Data collection. The data collection lasted eight days (8hours/each) during weeks 10 and 11 of 2022. The data collection period was the same as the construction workers' working hours, from 06:00 to 14:00 (see horizontal axis in Figure 1). Coffee break was from 09:00 to 09:15, and lunch break was from 11:30 to 12:00. The BWS technique was applied in the carpenter trade in charge of the gypsum installation, including a total of 4 workers (representing a sample of N=4). According to CII [27], the required number of observations per 30 minutes is 12 for a site with 0-50 workers (see goal line in Figure 1). After completing eight days of data collection, 1,567 samples were recorded with a 95% confidence interval of ± 5%. A stabilisation curve of the share of observations of the production codes was created to provide a visual check of the accuracy of the collected data (see Figure 2). The curve stabilises at 30% after around 1,037 observations.

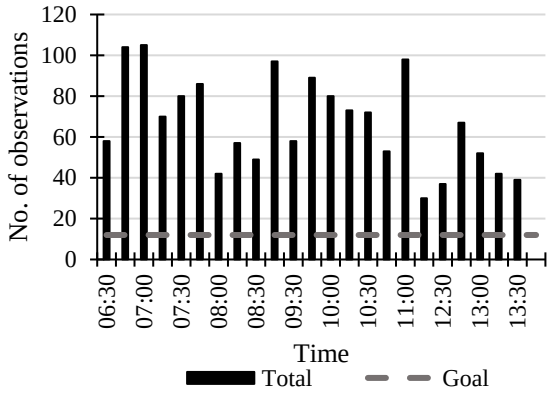

Figure 1: Number of observations conducted on the carpenter trade (n=1,567).

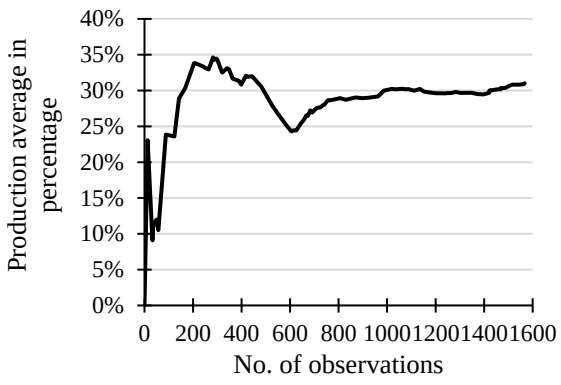

Figure 2: Stabilisation curve of the observations conducted (n=1,567).

3.2.3 Step 3. Data analysis. The observations were grouped into 15 minutes intervals to visualise the work time distribution throughout the workday. The observations were also grouped into the days of data collection. Adopting the BWS codes allowed the authors to simulate a scenario reducing the distribution of time of the categories that would be reduced if MTO boards were adopted.

3.3. Interview strategy for value chain analysis

Two types of interviews were conducted between October 2020 and May 2022 to explore possible scenarios for adopting a MTO technique. Interviews are a common method of qualitative data collection to explore the "views, experiences, beliefs and/or motivations of individuals on a specific matter" [28 p.292]. Fifteen semi-structured interviews (SSI) [29] were held. Eleven interviews with Saint-Gobain employees in Denmark, Sweden, Hungary and the Netherlands were conducted. These employees had either played a critical role in developing MTO solutions in other countries (see description of test projects in Section 2.2) or are involved with sales and customer services and would thus be relevant for delivering MTO solutions in Denmark. Interview questions aimed at understanding the role of key actors in the value chain and their interactions, both in the current value chain with standard gypsum boards and the piloted MTO solutions (see section 2.2). Four semi-structured interviews with value chain partners involved in the planning, design, contracting and installation of partition walls were conducted. Here, interview questions aimed at understanding actors' roles and work processes in partition wall construction, as well as requirements for using MTO gypsum boards.

In addition to the semi-structured interviews, three focus group interviews between January and October 2021 were held in Copenhagen, Denmark, with eight participants (participation, see Appendix 2). Focus interviews are useful to generate information on collective views and clarify views through discussion and feedback of participants in their interaction [28]. Participants were employees of

companies along the value chain (i.e. building developer, installer, contractor) and Saint-Gobain. Some of these participants have also participated in the semi-structured interviews. Focus group interviews helped to verify and improve the authors understanding of current actors in the value chain, their roles and potential scenarios to offer MTO. During the interviews, presentations of scenario illustration with and without MTO were discussed. A first draft of scenario illustrations was prepared by the first author of this paper together with a Saint-Gobain employee based on the insights gained from interviews with employees in Denmark, Sweden, Hungary and the Netherlands. Focus interviews and semi-structured interviews were used to revise illustrations in multiple rounds to improve their accuracy and integrate new insights gained. This process was supported through feedback of Saint-Gobain employees and final drawings were verified with three employees (in marketing, digital solutions, and technical sales).

4. Findings

4.1 Work Sampling results

The results of the work sampling can be seen in Figure 3 and 4. The observed share of time spent on production tasks was 31%. 25% of time was spent on preparation, and 23% on transportation. Waiting constituted 8% of the time, transportation 7%, and the remaining 6% of work time was spent on talking. Looking closer at the preparation category, the results show that four of the 13 activities observed within this category account for 87% of the total time spent on preparation tasks. These four preparation tasks are C301 Cutting gypsum with knife, C306 Measuring with ruler, C307 Waste handling, and C308 Fixing equipment. Except for the latter, these are the categories believed to be significantly reduced in a scenario where MTO gypsum boards are provided. Figure 4 represents the possible time distribution of the six work categories in the new scenario. Assuming that minor adjustments to the gypsum boards are still needed, the three categories C301, C306, and C307 are not eliminated, but can be reduced by 90% (e.g., 138 observations of the C306 to 14 observations). This reduction would result in a change in preparation time from 25% to 12%. Assuming the time saved on preparation tasks will be distributed proportionately among the other work categories, a rise in production from 31% to 36% would ensue from the change.

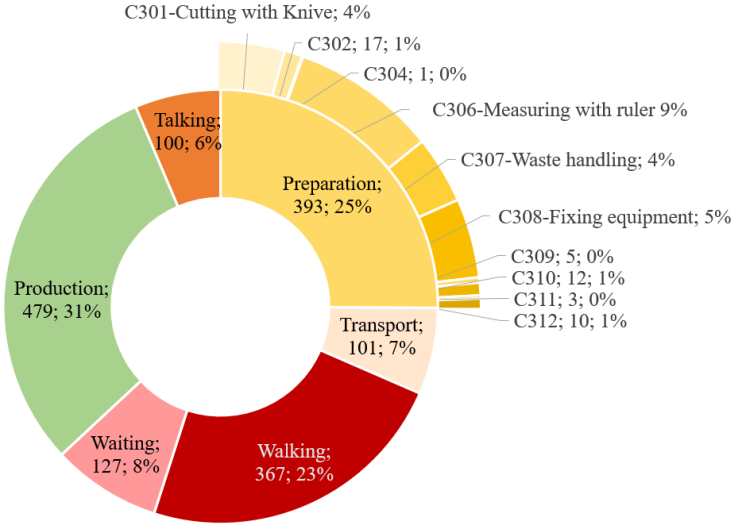

Figure 3: Totals observed on the jobsite (n=1,567) with a detailed showing of the preparation categories.

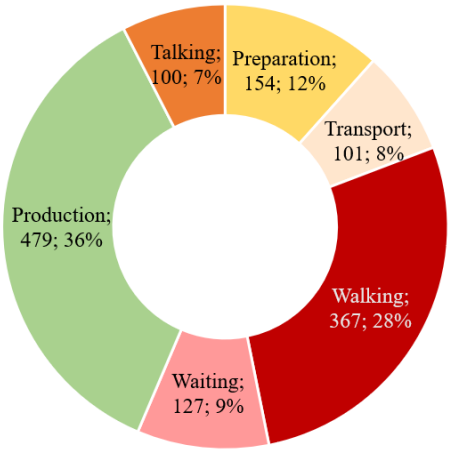

Figure 4: Possible scenario using MTO gypsum boards (n=1,328).

4.2 Value chain analysis

Two value chain scenarios of how MTO gypsum boards (i.e. cut to right length) could be offered in the Danish market were identified (Figure 5 and 6). Scenarios represent simplified archetypes that focus on interactions around the detailed design, ordering, and manufacturing of partition walls (i.e. between the architect, contractor, manufacturer).

One possible scenario, named Scenario 1, is a free service to contractors. *Contractors* order MTO based on the detailed design of the architect (Figure 5). This way of providing MTO is already used in few projects in Denmark (ca. 4% of Saint-Gobain Denmark's project sales) [30]. A common challenge that Saint-Gobain employees experience to deliver MTO is that the design material of partition walls (2D drawings) is unfinished or contains mistakes [31, 32]. Typically, only the manufacturer has the technical knowledge to accurately develop and optimise the design until suitable for MTO production. It often requires several rounds of clarification between the material *manufacturer*, *contractor*, and *architect* until the detailed design has the required quality.

A second MTO scenario, named Scenario 2, could be an integrated product delivery [21, 33] as piloted in projects in Sweden and in the Netherlands (see Section 2.2.). In integrated product deliveries, the supplier takes a higher degree of responsibility and combines industrial products with services at different stages of the products' life cycle e.g., in the early planning [34]. Typically, standardised products are customised to customers' needs [35] with a focus on solutions rather than products [34, 36]. Specialised knowledge by the manufacturer has the potential to reduce complexity of the planning process and improve results [34]. Interviews with Saint-Gobain employees in Sweden indicated that if such a model would be employed, Saint-Gobain could prepare the detailed design based on the room functions specified by architects (see Figure 6). Based on interviews with Saint-Gobain's technical sales service, this could ensure design material of the required quality to determine the right sizes for MTO and improve buildability at the construction site. Next to the improved design, a potential benefit could be a reduced need for communication between *contractor*, *architect* and *installer* compared with the first scenario. *Installers*' work could be facilitated through assembly guidelines prepared by the *manufacturer* (see examples described in Section 2.2).

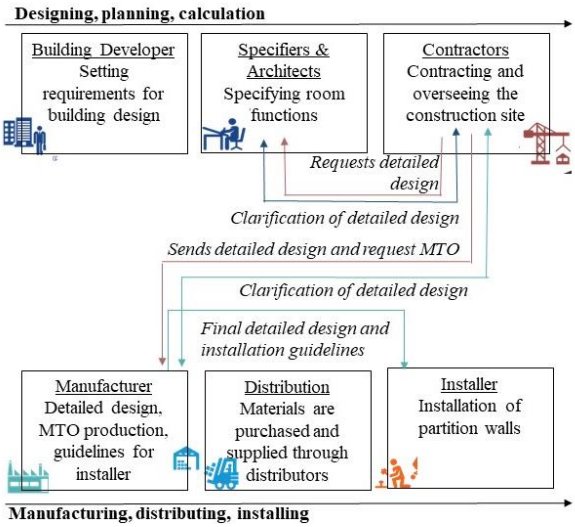

Figure 5: Scenario 1 of value chain scenario with MTO as a free service.

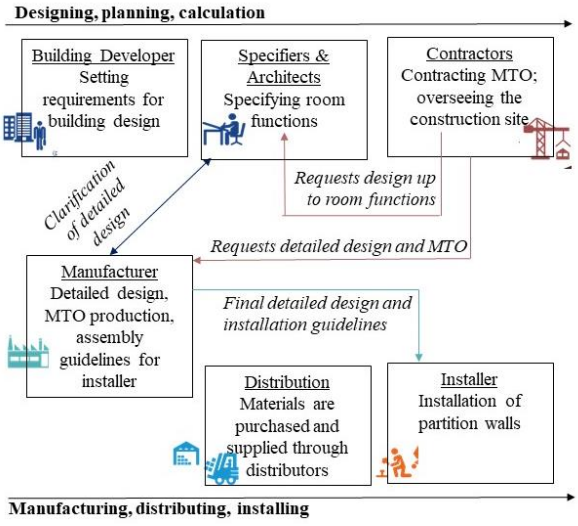

Figure 6: Scenario 2 of a value chain scenario with MTO as an integrated product system.

5. Discussion and conclusion

The present study aimed to understand the potential productivity improvements of the gypsum installation process from adoption of MTO gypsum boards. The time study results suggest that adoption of MTO gypsum boards, in theory, could be a more sustainable renovation concept (e.g., 13% less installation time because of less cutting and measuring time at the construction site). This possible scenario can also generate a cleaner and safer job site. Based on interviews with value chain actors, two possible scenarios for delivering MTO gypsum boards in the Danish market were identified. However, the interviews also revealed significant challenges to industry adoption of MTO. Scenario 1, as a free

service, has long lead times and is financially unattractive for the manufacturer. Scenario 2, as an integrated product system, requires new practices of actors in the chain. High fragmentation of the construction value chain into different trades and responsibilities, typically prevents joint optimisation of processes and introduction of new practices.

This study presents several limitations. The breakdown work sampling has been only conducted on one construction project. Gypsum installation in renovation projects with other characteristics (e.g., with smaller rooms, multiple floors, larger crew size) could result in a different average for the share of time on production versus preparatory activities. Time reduction of 90% of preparation activities from MTO gypsum boards is based on the authors' assumptions. The real reduction should be investigated in future studies. Moreover, it should be noted that the MTO scenarios represent the first suggestion exclusively based on the experiences of interviewees in this study. Further validation and feedback from other value chain partners is needed to increase the external validity of the two scenarios (e.g., in the case of different types of contractors). Other scenarios of how MTO could be adopted in the Danish market (e.g., through procurement practices of the building developer) should be explored.

Future research is needed to identify potential time savings for different types of renovation projects. A breakdown work sampling should be conducted on a case with MTO gypsum boards to investigate potential time savings compared with the results obtained in this study. Reduction of waste through MTO and experiences of craftsmen and building site managers should be assessed to verify sustainability potential. Technical questions on control measurements and tolerances and suitability of different renovation projects for MTO should be addressed, as well as implications on organisational capabilities (e.g., digital processes to reduce lead times for approval of design material and business model for the manufacturer (e.g., ability to take responsibility for MTO delivery).

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Appendix 1 - List of participants in semi-structured interviews (SSI) and focus group interviews (FG)

Type of interview	Position	Company	Role	Country	Date
Semi-structured Interviews					
SSI Num.1	Business Unit Manager Interior Solutions	Saint-Gobain	Delivered MTO solutions	NL	Oct 2020
SSI Num.2	VDC Implementation Manager	Saint-Gobain	Technical development of MTO in Sweden	H	Oct 2020
SSI Num.3	Digital Solutions Manager	Saint-Gobain	Concept development of MTO in Sweden	DK	Oct 2020
SSI Num.4	Public Relation Manager	Saint-Gobain	Representing company interests in industry and policy	DK	Oct 2020
SSI Num.5	Head of Sales	Saint-Gobain	Responsible for sale strategy and team	DK	Nov 2020
SSI Num.6	Public Relation	Saint-Gobain	Responsible for customer contact in MTO solution	SE	Nov 2020
SSI Num.7	Strategic SAP & Business Process Lead	Saint-Gobain	Responsible for ordering of a MTO solution	SE	Nov 2020
SSI Num.8	Head of Technical Sales	Saint-Gobain	Advise for detailed design of partition walls	DK	Nov 2020
SSI Num.9	Director	Installer	Managing installation business	DK	Jan 2021
SSI Num.10	Architect	Architect	Designing buildings	DK	April 2021
SSI Num.11	Chief consultant	Public building developer	Integrating sustainability initiatives into municipalities' construction projects		
SSI Num.12	Junior consultant				
SSI Num.13	Technical Sales	Saint-Gobain	Advise for detailed design of partition walls	DK	May 2022
SSI Num.14	Technical Sales				
SSI Num.15	Head of Technical Sales				
SSI Num.16	Head of Renovation	General contractors	Overseeing renovation projects for the Danish market	DK	May 2022
Focus Group Interviews					
FG Num. 1,2,3	Chief consultant	Public building developer	Integrating sustainability initiatives into municipalities' construction projects	DK	Nov, 2020; Jan, Aug 2021
FG Num. 1,2,3	Junior consultant				
FG Num. 1,2,3	Director	Installer	Managing installation business	DK	Nov, 2020; Jan 2021
FG Num. 1,2,3	Head of renovation department	General contractor	Overseeing renovation projects for the Danish market	DK	Nov, 2020; Jan 2021
FG Num. 1,2,3	Sustainability manager	General contractor	Devising and implementing sustainability strategy	DK	Jan, Aug 2021
FG Num. 1,2,3	Public relations manager	Saint-Gobain	Representing company interests in industry and policy	DK	Nov, 2020; Jan, Aug 2021
FG Num. 1,2,3	Project manager		Leading project on MTO development	DK	Nov, 2020; Jan, Aug 2021
FG Num. 1,2,3	Upstream business developer		Business development upstream	DK	Nov, 2020; Jan, Aug 2021

Appendix 2 - Categorisation of the codes adopted for the study

#	Main work-activities categories					
	Production	**Talking**	**Preparation**	**Transport**	**Walking**	**Waiting**
1	101-Screwing	201-Talking about the process	301-Cutting with knife	401-Board by hand	501-Walking for having breaks	601-Waiting for material
2	102-Grouting	202-Talking without any (known) purpose	302-Cutting with machine	402-Board by forklift	502-Walking for materials and tools	602-Waiting for a coworker
3	103-Stapling		304-Measuring with laser	403-Board by lift platform	503-Walking without (known) purpose	603-Waiting without any (known) purpose
4	104-Sparting		306-Measuring with ruler	404-Tools or equipment	504-Using platform	606-Waiting for tools
5	105-Hammering		307- Waste handling			
6	106-Installing		308-Fixing equipment			
7	111-Screwing in steel		309-Cut-out			
8			310-Cutting steel band			
9			311-Using waterpass			
10			312-Cutting stell			
11			314_Measuring steel			