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Why do some projects prefabricate MEP while others do not?

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Abstract

Research Question: Why do some projects prefabricate mechanical, electrical, and plumbing (MEP) systems while others do not?

Purpose: Most of the literature on MEP prefabrication is focused on its benefits, implying prefabrication is a rational choice, yet adoption rates remain low. The purpose of this study is to increase understanding in prefabrication decision-making.

Research Method: Multiple case study research with a qualitative approach.

Findings: The decision to prefabricate can result from a long lean implementation process or as an individual method to overcome a specific problem. Shortening cycle times and removing task dependencies to shorten the critical path are motivators for choosing to prefabricate. Additionally, cost savings during the project and improved productivity at the portfolio level are reasons for prefabricating. Tight schedules, late contractor involvement, and higher direct costs are reasons for not prefabricating, although cost- and schedule-related benefits are simultaneously acknowledged as benefits of prefabrication.

Limitations: The study is limited by the low number of case projects and its emphasis on the Finnish market where MEP prefabrication is uncommon.

Implications: The results support fact-based decision-making by highlighting reasons for prefabricating and the limitations of the evaluation methods. Additionally, required changes to production systems to realize the benefits of prefabrication are shown.

Value for practitioners: The perceived benefits of prefabrication increase in certain circumstances, such as when takt production is utilized. The perceived benefits decrease when prefabrication is considered late in the process, is used instrumentally, or is

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isolated from other lean approaches.

Keywords: prefabrication, choosing by advantages (CBA), Lean Construction

Paper type: Full paper.

Introduction

Emphasis has been put on the flow and value concepts of the transformation, value, flow theory (Koskela 2000), and industrialization as one possible solution toward construction improvement has emerged as an example derived from the manufacturing industry (Warszawski 1990; Mansoori et al. 2024). The fully industrialized mass production of buildings has not been widely adopted despite decades of trial and error. During that time, prefabrication as a partial implementation of industrialization has progressed, albeit slowly. Notable successes include the widespread use of concrete elements and architectural features such as façade panels (Sacks et al. 2004). In contrast, mechanical, electrical, and plumbing (MEP) systems have not experienced a similar gradual trajectory of prefabrication adoption. Even in otherwise advanced construction markets, MEP systems are typically assembled on-site by skilled tradespeople, with limited integration of industrialized methods (Lavikka et al. 2021). MEP systems are a particularly relevant focus area due to their substantial share of total construction costs, growing system complexity, reliance on craftsmanship, critical role in indoor environment, and building energy efficiency (Khanzode, 2010). These characteristics make them challenging and increase the potential impact of prefabrication.

Prefabrication means moving work from the construction site to a factory environment, thereby reducing installation time on site, and it has been suggested to solve the problem of low productivity and poor quality in construction (Pan et al. 2008). The documented benefits associated with prefabrication include less time and material waste, better ergonomics, shorter cycle times, fewer accidents, improved productivity, and better quality (Eastmann and Sacks 2008; Poirier et al. 2015; Lavikka et al. 2018). In addition to these non-monetary benefits, direct cost savings have also been reported, although evidence is contradictory (Khanzode et al. 2008; Jang and Lee 2018). Based on these studies, the adoption of MEP prefabrication seems like an obvious choice.

Low adoption rates regardless of the apparent advantages suggest that prefabrication is not chosen merely based on the reported benefits. While studies have extensively documented the social, political, technical, and economic barriers to prefabrication adoption (Li et al., 2017; Dodge, 2020; Lavikka et al., 2021; Zhang et al., 2022), examples of successful implementations suggest that these barriers can be overcome and that project-specific considerations potentially play a more significant role than previously assumed (Alhava et al., 2024). The study of Lavikka et al. (2021) is limited by focusing on interest group interviews on a general non-project-specific level. The research literature lacks an explanation as to why some companies choose to implement MEP prefabrication and succeed in it, while others deem it unprofitable or impossible. In this research, five cases are evaluated. Two of the cases decided to construct on site, and three of the cases decided to prefabricate. Differences in the reasons contributing to these decisions are analyzed, answering the following research question: **What are the differences in decision-making processes resulting in the adoption or rejection of MEP prefabrication?**

The results suggest that prefabrication is not chosen in isolation from other lean methods to achieve the promised benefits. Those who chose to prefabricate did it to achieve a specific goal (to comply with a tight schedule or shorten the critical path) as part of a broader strategy or as the natural next step in a long lean implementation process. Conversely, considering prefabrication as a method to achieve cost benefits on a project level seems to result in its rejection. These results imply that if previous lean implementations have not been carried out, cost analysis will, likely correctly, indicate higher direct costs, resulting in on-site construction. On the other hand, if the project is already using other lean methods, such as takt production, or is striving to shorten cycle times in the long run, prefabrication might benefit these efforts. The academic and industrial contribution of the paper is culminated in the documented drivers influencing the adoption of prefabrication as means to reduce construction durations.

Literature Review

The terms prefabrication, offsite construction, modular construction, preassembly and the like can be used interchangeably, although the meaning can vary by geographical location or context. In this paper we use the term prefabrication to describe an activity where factory made components are used to build assemblies or subassemblies that are installed to correct locations on construction sites. This can mean small subassemblies consisting of individual pipe installations with bends and hangers or large assemblies like district heating substations, ventilation shafts, or entire modular technical rooms. Prefabrication as we use it does not mean manufacturing of individual components such as a pipe, a duct, or a T-branch.

Studies have documented multiple obstacles hindering or preventing the adoption of MEP prefabrication. The following obstacles in the adoption of MEP prefabrication have been reported by Li et al. (2017), Dodge (2020), Lavikka et al. (2021), Zhang (2022), and Lopez et al. (2022):

- Prefabrication requires detailed designs earlier in the process, necessitating early design freezes. In traditional procurement, designs are not detailed enough for bidding prefabrication accurately.
- Project type not applicable for prefabrication
- A lack of prefabrication procurement knowledge and resistance to change by contractors and owners.
- Direct costs are the main bidding criteria and prefabrication costs too much.
- A lack of detailed standardized/modular designs due to a lack of capabilities and the custom of designing one-of-a-kind buildings.
- Contract and union agreement boundaries.
- A lack of flexibility (design revisions).
- A lack of local prefabrication shop and trained workforce for installation.

- Increased logistics considerations, transportation, lifting, protection, storage, site access.

MEP prefabrication has been defined as a systemic innovation (Lavikka et al., 2021). And research for systemic innovations in construction shows that integrated supply chains on project level and vertically integrated companies enable adoption of systemic innovations (Hall et al., 2018; Hall et al., 2019).

Objectively balancing the benefits and obstacles to decide whether to prefabricate is not simple; hence, various evaluations methods have been introduced. Based on previous research, Chauhan et al. (2019) proposed a choosing by advantages (CBA) based method for comparing MEP prefabrication with on-site construction. Their proposed model answered the need for transparency in evaluating non-monetary benefits in addition to direct costs. The need for such a framework was derived from the overemphasis on direct costs and the difficulty in translating other benefits into monetary benefits reliably. A study by O'Gorman et al. (2023) also showed that there is a need to evaluate the non-monetary aspects in parallel with monetary aspects. In the CBA method, these non-monetary benefits are ranked between on-site and prefabrication alternatives to determine their relative advantage over each other. Namely, for each relevant criterion the advantageous alternative is selected, and this alternative is given an importance score reflecting the importance of given criterion. Finally, prefabrication is compared to on-site construction by combining the direct costs and relative advantage as sum of importance scores in one figure (Suhr 1999; Arroyo 2012). CBA is an applicable and superior decision-making framework as its supports clear identification of preferred advantages, transparency, and collaborative decision making (Arroyo et al., 2014a; Arroyo et al., 2014b).

The need for detailed design is a significant theme in decision-making as it is necessary but also causes additional costs. Design for manufacture and assembly (DfMA) is a method of detailed design that integrates manufacturing and assembly considerations in the design phase (Bogue, 2012). By designing in detail for both the prefabrication of components and assembling them on site, DfMA reduces the dependency on traditional, labor-intensive construction methods and minimizes waste and construction time (Gibb and Isack 2003). It promotes modularity and standardization, enabling repeatable processes and faster project delivery, which are essential in modern construction practices aiming for sustainability and efficiency (Goodier and Gibb 2005). The product of DfMA is typically a design with a high level of detail (LOD) and an accurate bill of materials.

In addition to barriers, there are also enabling factors, such as takt production, for choosing to prefabricate. Takt production is a time-based system that segments work into fixed intervals (takt times) and relies on a steady flow of materials and components to maintain its rhythm (Dlouhy et al. 2016). Takt production and prefabrication benefit from each other by enhancing the efficiency and productivity of construction (Chauhan et al. 2018). Prefabrication supports takt by supplying preassembled components that are manufactured off site in controlled environments, ensuring consistent quality and reducing the variability often seen in on-site construction (task duration and geometrical variation) (Jaillon and Poon 2008).

This synergy shortens project cycle times, leading to cost savings and better quality (Eastman et al. 2008).

Research Methods

Multiple case study research with a qualitative approach was selected as the research method for this study. Case study research is well suited for answering how and why questions and generating a deep understanding of the studied phenomenon (Yin 2018). The cases were selected using purposive sampling to address the research question. The cases were selected from construction companies participating in a collaborative research project. Ongoing projects were discussed with the companies and the most suitable according to availability and the selection criteria were selected. Purposive sampling is suitable for selecting the most informative cases when working with a small sample size. The following criteria were applied for case selection:

1. **MEP prefabrication has been implemented or has been considered for implementation**

Prefabrication is defined as any kind of systematic preassembly or manufacturing of installations that is not done in a typical on-site installation manner. Technical solutions where prefabrication is already common were excluded (examples include district heating substations, air handling units, and electrical switchboards). Previous consideration of prefabrication is also required for non-prefabricating cases to investigate the reasons for decisions. Selected cases should show evidence of sufficient consideration of prefabrication, for example extensive discussions, preliminary designs, cost comparisons, or other forms of systematic evaluation.

2. **Projects of different levels of adoption of MEP prefabrication**

It is important to differentiate between projects that use prefabrication in a single installation type from those that prefabricate multiple systems. The scope of implementation might affect the decision-making process as the number of issues for consideration changes accordingly.

3. **Different building types**

Choosing different building types gives an understanding of how and if different building types affect the decision-making process. Different building types have different levels of repetition and complexity. Hotel and apartment buildings are relatively simple, with a high degree of repetition, whereas hospitals, for example, are complex environments with a multitude of systems and varying degrees of repetition.

4. **Availability of data and people for interviews**

The project must be ongoing or recently finished to guarantee the availability and reliability of data. Projects that finished a long time ago can suffer from difficulty in reaching project members, unreliability of recollected data, and advancement of practices affecting the usefulness of experiences. In addition to having people available for interviews, it is important to be able to access the documentation and construction site when possible.

5. Rationale for Case 1

Choosing only cases that have already decided rules out a significant number of projects and overemphasizes projects where prefabrication is known. To overcome this potential bias, one case was selected to be a project where prefabrication had not been considered but where project members were willing to evaluate its applicability.

Data Collection and Analysis

The data were collected through semi-structured interviews, document analysis, and participant observation. Semi-structured interviews allow for an enhanced depth of understanding by presenting open-ended questions and being able to further question important arising themes (Brinkman 2014). For each project, one key project member was initially interviewed, and snowball sampling was used to identify potential new interviewees (Biernacki and Waldorf 1981). Interviews were conducted until no new relevant informants were identified. Interviews for cases 1, 3, 4, and 5 were conducted by the first author. Interviews for case 2 were conducted by the first and second authors. Document analysis and site visits were arranged as part of the interviews to support the discussion. Multiple sources of data (interview, document, observation) and multiple case projects support the validity and reliability of findings as two different sources of triangulation, namely method triangulation and source triangulation (Patton, 1999). The research method is illustrated in Figure 1.

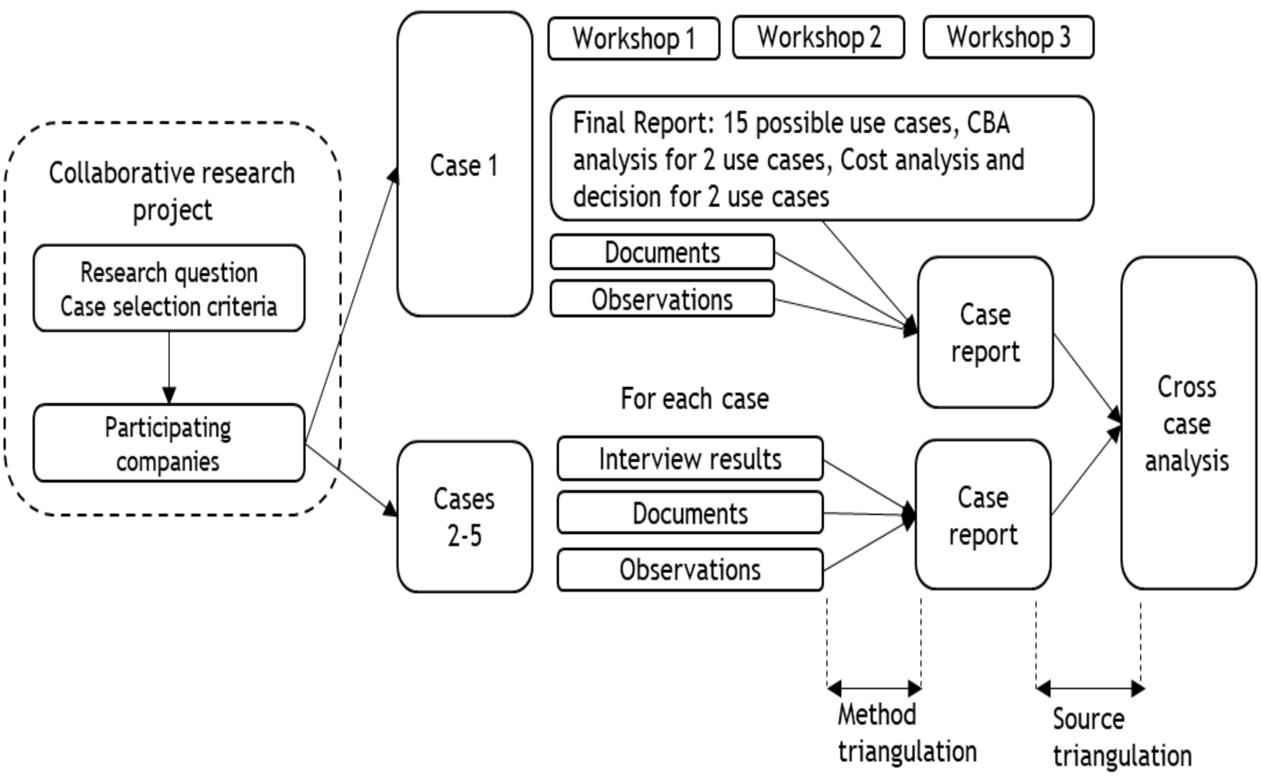


Figure 1: Research method and steps.

Case 1 differs from other cases, since the prefabrication consideration was done with the researcher. For Case 1, workshops, where the first author was a participating observer and facilitator, were arranged to determine possibilities for prefabrication in the project. During the first workshop, the project and project people were introduced. Possible use cases for prefabrication were identified and listed. In the second workshop, two of the most attractive alternatives were chosen for further analysis by means of CBA. The factors for CBA consideration were decided by the participants. In the third workshop, the costs for the two alternatives were determined, and a final decision and the reasons for the decision were discussed. For Case 1, data were collected as notes during and after the workshops. Additionally, data consisted of all the documents and calculations drafted during the workshops. These documents included the prefabrication plan, CBA analyses, cost analyses, and project documentation. The prefabrication plan, CBA and cost analyses were created during the workshops in collaboration with the participants with the first author as secretary. Data from the semi-structured interviews in Cases 2–5 were recorded in notes during and immediately after the interviews.

In Cases 2, 3, 4, and 5, the consideration to use prefabrication had already been made, and research was focused on determining the process and the reasons affecting the final decision, retrospectively. A summary of the studied projects and the data collection methods used are presented in Table 1.

In total, 26 people were interviewed, the interviews lasting from 30 to 180 minutes. The themes for the semi-structured interviews were determined based on literature and are presented below. The interviews and workshops were held in person for all other than case 4, where the interviews were remote via Microsoft Teams. All the participants from the workshops in Case 1 and interviews in cases 2-5, along with their roles in the projects, are listed in Table 2.

- Project outline
- Interviewee background and role in project
- Previous experience in MEP prefabrication
- What was prefabricated in the project
- Why did the project team choose to prefabricate, and how was the decision made
- Were the anticipated benefits of prefabrication realized
- How was the design, production, and installation done for prefabrication
- How did prefabricating affect the rest of the project

The data from interviews, document review and observations were analyzed and reported first on case project level. This was the first level of triangulation, combining multiple information sources on case level to confirm the findings as converging lines of inquiry (Yin, 2018). Then a cross-case analysis, using deductive reasoning, was conducted to systematically analyze the cases to find commonalities and differences. This was the second level of triangulation where the validity of findings within one case are strengthened by supporting evidence from other cases (Yin, 2018). Finally, the findings from cross-case analysis are discussed in relation to existing knowledge. The interviews were the main source of information. Data from documents and observations were used to support understanding and confirm findings from multiple sources. The documents included design documents (MEP and ARC designs), BIM-models, schedules, and prefabrication designs.

Table 1: Summary of the case projects and data collection methods.

	Case 1	Case 2	Case 3	Case 4	Case 5
Project description	New construction Educational building GC was interested in studying possibilities of prefabricating	Renovation Apartment building GC implemented prefabrication to shorten takt and cycle times	New construction Hospital Alliance studied utility of prefabricating shafts	Renovation of 100-year-old building from office to hotel Construction manager chose to prefabricate to shorten cycle times	New construction Hospital GC wanted to prefabricate corridor installations
Procurement	Collaborative life cycle project	Design Bid Build	Alliance	Project management contract	Collaborative
Country	Finland	Finland	Finland	Finland	Sweden
Scope of MEP prefabrication	No prefabrication	All installations in apartments and risers	Ventilation shafts for project phase A No prefabrication for phase B	Vertical shafts to bathrooms	No prefabrication
Previous experience with prefabrication	None	Multiple similar projects	Ventilation shafts	None	From residential construction
Data collection methods	Three workshops (determination of possible prefabrication, comparison of non-monetary factors by CBA, cost comparison) Document review	Semi-structured interviews Document review	Semi-structured interviews in two parts Document review	Semi-structured interviews Document review	Semi-structured interviews Document review
Site visits	One visit	Two visits	One visit	No (finished project)	One visit

Table 2: Workshop participants and their roles in Case 1 and interviewees in Cases 2, 3, 4, and 5.

	Workshop participants	Role in project
Case 1	MEP foreman 1	Electrical
	MEP foreman 2	HVAC
	Project manager 1, GC	
	Project manager 2, GC	
	MEP designer	Design project manager
	MEP expert, GC	Initial design
	Construction manager, GC	
	Interviewees	**Role in project**
Case 2	Construction worker	MEP (on site)
	Construction worker	Prefabrication
	Designer	MEP (prefabrication and site installations)
	Team leader	Foreman on site (workers)
	Group leader	Foreman on site (team leaders)
	Development manager	Development
Case 3	Development manager	Safety and improvement
	Construction manager	HVAC manager
	Construction manager	HVAC manager
	Prefabrication manager	MEP prefabrication
Case 4	Supervisor	HVAC and automation
	Design manager	HVAC design
	Construction manager	HVAC installations on site
	Prefabrication manager	MEP prefabrication
	Group leader	Foreman on site (team leaders)
	Development manager	Development
Case 5	Manager	MEP manager
	Group leader	Foreman on site
	Support system provider	Mockup design for prefabrication, hanger design, and delivery

Results

Case 1, cost is king

Prefabrication was evaluated in the construction of a new educational building in Finland. In the first of three workshops, a prefabrication program was drafted recognizing 15 possible use cases of MEP prefabrication in the case project (Table 3). This included discussions of design scope, the requirements for a special prefabrication contractor, site and design schedules, material acquisition, site logistics, safety, and contractor capabilities. At this point, none of the use cases were deemed impossible. A schedule for design and construction was seen as problematic in many cases. In some instances, elements should be installed during frame erection. This was not possible due to the project and design schedule.

Table 3: 15 use cases identified in workshop 1.

1	Ventilation shaft	9	Horizontal pipe installations (heating, cooling, sprinkler)
2	Door frame	10	Technical room, gas, volumetric element
3	Technical room, ventilation, volumetric element	11	Compressed air system, compressor, pressure vessels etc.
4	Technical room, heating, volumetric element	12	Partition wall with electrical installations, panel element
5	Toilet element, volumetric element	13	Pump and valve assemblies for AHUs
6	Sink element, panel with installations	14	Corridor element, horizontal ventilation ducts
7	Solar panel element, roof or facade	15	Combined electrical and automation board along with cabling for AHUs
8	Technical panel with lighting, cooling and heating for ceiling installation		

In the second workshop, the two most suitable use cases, (i) a ventilation shaft with HVAC systems and (ii) a fully equipped door frame with electrical systems, were selected for detailed CBA analysis. The ventilation shaft would consist of a supporting structure containing all ductwork within the shaft. The shaft element would be either one or two floors high. These elements were to be installed during frame erection and manufactured in a separate location by the already selected contractor. The door frame would include electrical installation in the panel adjacent to the door, including lighting switches, sensors, displays, and indicators. Both installations are typically made on site.

The CBA compared on site construction to prefabrication separately for both alternatives. For both evaluations, the prefabricated alternative was decisively preferred over on-site construction in the case of non-monetary factors. In the case of the ventilation shaft, five out of seven benefits were assigned to the prefabrication alternative. In the CBA analysis, prefabrication had 270 importance points against 90 for on site. For the doorframe, all benefits were assigned to the prefabrication alternative, the total importance points being 320 against zero for on site. The three most important factors in both evaluations were assessed to be safety, ergonomics, and material waste. The detailed evaluation is presented in Tables 4 and 5 for the ventilation shaft and the door frame, respectively.

The third workshop focused on determining the direct cost differences and adding the cost component of the CBA. For the ventilation shaft, the direct cost of prefabrication was estimated to be 6% more expensive. For the door frame, the prefabricated version was estimated to be 11% more expensive. Costs related to factors evaluated in the CBA were not calculated due to the lack of an objective method for determining costs. The resulting CBA analysis is presented in Figure 2. In both cases, the prefabricated alternative scored significantly higher and was only slightly more expensive.

Table 4: CBA analysis of ventilation shaft, prefabrication versus on-site construction.

Factors	Prefabricated ventilation shaft	Imp.	On-site ventilation shaft	Imp.
Material waste	Attribute: Causes less waste. Better utilization of cut pieces. Cleaner storage and handling. Adv: Causes less waste.	40	Attribute: Causes waste due to unused cut pieces and damaged ducts. Waste in insulation.	-
Safety of workers and environment	Attribute: Risks in lifting of the elements. Decreases working in areas with a risk of falling. Adv: Smaller safety risks overall.	100	Attribute: More work in open shafts. Risk of falling or dropping tools and materials.	-
Ergonomics	Attribute: Possibility to work in positions of better ergonomics. Horizontal installation of ducts. Adv: Better working positions.	60	Attribute: Working in high and cramped spaces. Especially insulation is challenging. Very small spaces.	-
Quality	Attribute: Supports and insulation are easier to install in steel frames. Adv: Fewer quality issues.	50	Attribute: Duct supports need to be designed on site to fit the local conditions. Variations in installation.	-
Flexibility of design	Attribute: Design changes are more expensive or impossible.	-	Attribute: Design solution can be changed up to the point of installation. Installation later compared to prefabrication. Adv: More flexible solution.	50
Logistics	Attribute: Lifted immediately to the right location and installed. Less site storage. Adv: Ready installation quickly from delivery.	20	Attribute: Hauling large ducts from site storage to shafts is challenging.	-
Design schedule	Attribute: Design must be completed significantly earlier and takes more time due to increased LOD.	-	Attribute: Later installation and lower LOD. More available design time. Adv: More time for designing and, therefore, more flexibility in the design.	40
Total		270		90

Table 5: CBA analysis of door frame, prefabrication versus on-site construction.

Factors	Prefabricated door frame	Imp.	On-site equipped door frame	Imp.
Material waste	Attribute: Smaller risk for damage affects waste, a significant factor. Adv: Elimination of broken equipment during installation.	90	Attribute: More waste caused by equipment broken during installation.	-
Safety of workers and environment	Attribute: Fewer accidents. No working in high places. Cleaner site. Adv: Fewer accidents.	80	Attribute: Many openings drilled on site at high locations. Causes debris to surroundings.	-
Ergonomics	Attribute: Possibility to work in an ergonomic position and use industrial methods. Adv: Better working ergonomics.	50	Attribute: Working in high places. Unergonomic working positions.	-
Maintenance and flexibility for changes	Attribute: Door frames equipped with extra conduit pipes, allowing for easy addition later. Adv: Better flexibility during the life cycle.	60	Attribute: Only what is needed will be installed. Changes later are more difficult.	-
Logistics	Attribute: No need to store or transfer equipment on site. Adv: Less logistics and storage on site.	40	Attribute: Need to store equipment on site close to doors when door frames are opened.	-
Total		320		0

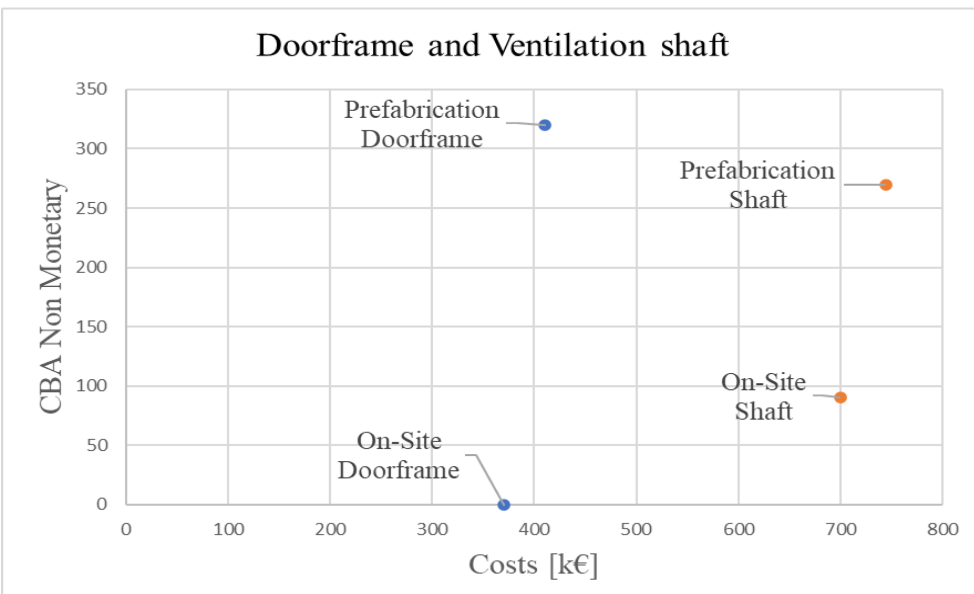


Figure 2: Effects of monetary and non-monetary factors of prefabricated and on site manufactured ventilation shaft and doorframe with electrical installations.

All participants agreed that based on these results, on-site construction would be selected in both cases. Competition for contracts being solely based on total cost was given as the reason for this choice; prefabrication would have to be the cheaper alternative to be chosen. The participants acknowledged that quality and safety affect costs. They had ranked these as important factors. However, they did not trust the cost savings to be sufficient in comparison to direct costs without calculations. Without experience in prefabrication, they found it difficult to estimate the magnitude of the cost saving. While there were no barriers preventing prefabrication, some aspects were found to hinder its adoption, including designer capability (detailed modeling and schedule), the construction schedule (designing concurrent to construction), and difficulties in evaluating possible savings from CBA factors in advance.

It can be argued that the owner might accept higher costs to achieve better quality, better safety, or shorter cycle times. This would require a comparison method to determine the difference between bids, and the evaluation criteria must be announced in advance. In this case, such criteria were not used and using such criteria is not common. The owner expects to receive identical quality in the requested timeframe from all the competing contractors, so it might be difficult to justify favoring one method over another, especially when the benefit is based on the subjective evaluation of one contractor. Especially important is to notice that the beneficiary of these advantages would mostly be the contractor. Presumably, quality problems are fixed before handover or during the guarantee period. Shorter cycle times reduce costs from the contractor, and, for the owner, faster handover might even cause unwanted costs if the building is not needed earlier.

Case 2, prefabrication enables industrial construction

The case company prefabricated MEP systems for apartment building pipeline renovations in Finland. A pipeline renovation typically consists of renewing all the MEP installations. Sewers, water pipes, heating systems, and ventilation ducts are rebuilt, and bathrooms are stripped to concrete surfaces and completely renovated. The prefabricated products included water, sewer, ventilation, electrical cables, heating, and suspended ceilings. The company had a goal of achieving competitive advantage by shortening cycle times and improving quality by introducing practices of industrial construction. The company is considered a pioneer in the application of flow and takt production in Finland.

The interviewees did not identify a specific consideration or decision leading to prefabrication. Instead, they described the company's journey to industrialization and how prefabrication was eventually a natural next step in reducing cycle time and improving productivity. Figure 3 illustrates the company's journey as reported by the interviewees. After adopting takt scheduling and a four-hour takt, the company noticed that further shortening of takt times and cycle times would require prefabrication, i.e. moving work away from the construction site.

As traditional construction drawings do not enable the creation of an M-BOM due to their low level of detail, separate designs for manufacture and assembly are needed. A detailer drafted high LOD designs using AutoCAD and their own library of manufacturer-specific parts.

All support systems were also designed, and possible clashes were resolved. These assembly drawings contained millimeter-level cut lengths. The reuse of designs from project to project reduced design time as the number of projects increased. Examples of traditional construction drawings and designs for manufacturing are presented in Figures 4 and 5. Figures 6 and 7 show the manufacturing and installation of underfloor heating.

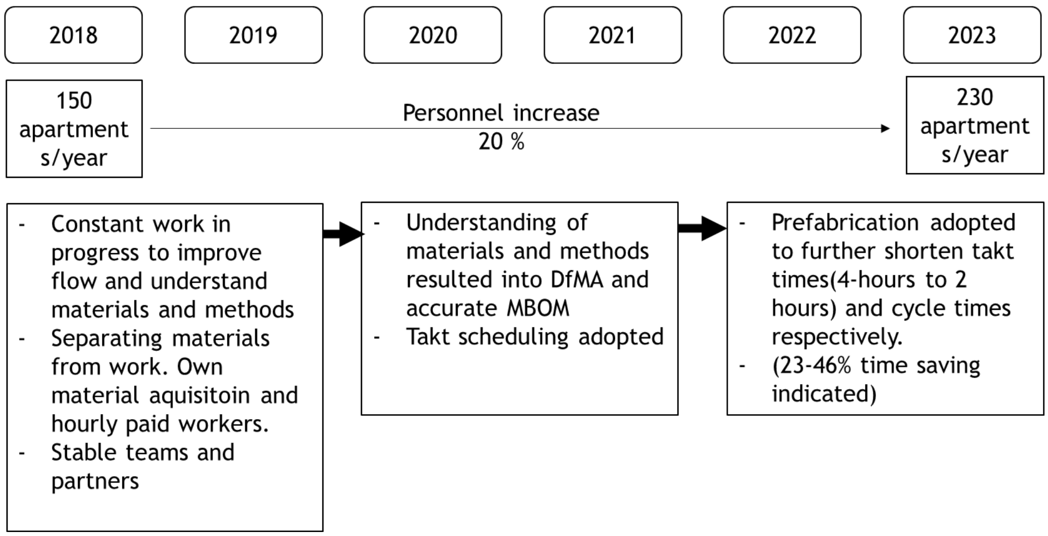
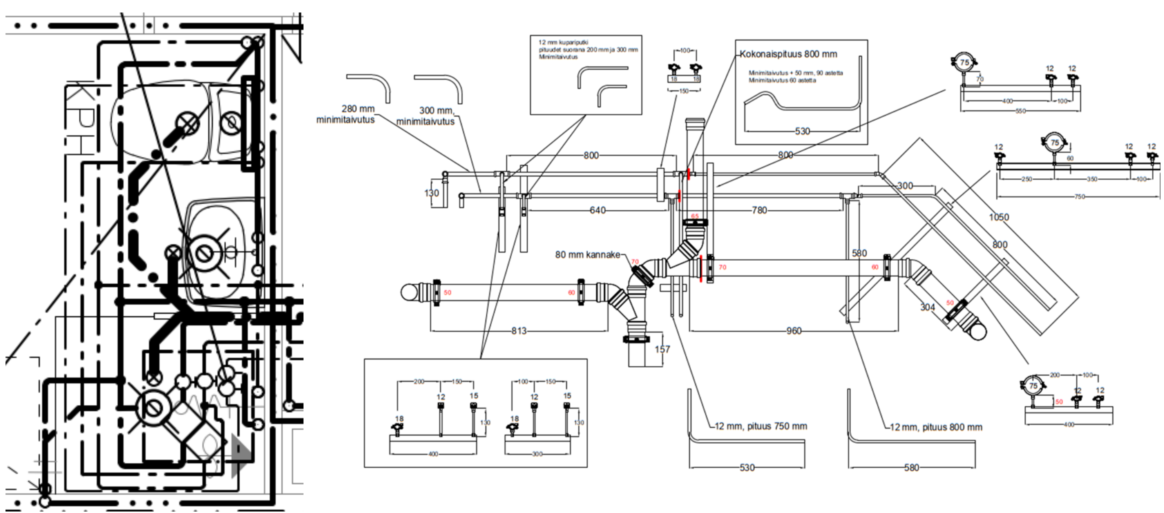
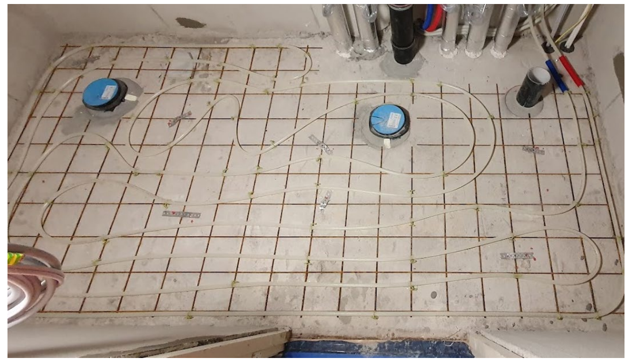


Figure 3: The company's journey to prefabrication through efforts to reduce cycle times.

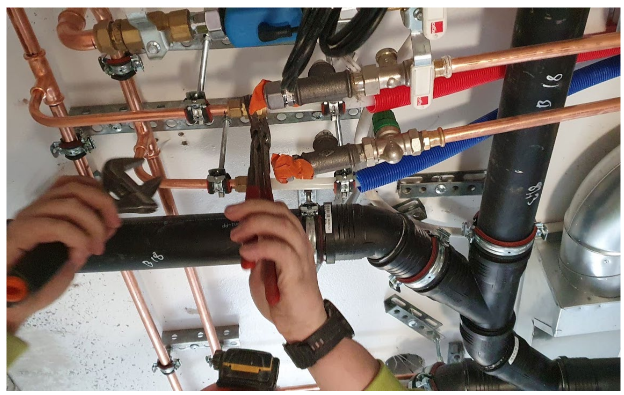
Fabrication was scheduled according to a takt schedule, and the work was divided into packages per takt area for one day. Figures 8 and 9 show subassemblies of pipes ready for transportation and the installation itself. Four different consolidation points (wholesale, factory, site warehouse, and workstation) were in use, and logistics were carried out by specialized personnel.



Figures 4 and 5: Figure 4 (left) is a traditional construction drawing for water and sewer installation (LOD below 200). Figure 5 (right) is a design for prefabrication (LOD 400) containing three subassemblies (separated by red lines in the drawing).

Figures 6 and 7: Cardboard template (1:1, prototype design) for laying underfloor heating pipes in one bathroom type and later installed prefabricated module (white pipes on steel net).

Figures 8 and 9: Prefabricated pipe elements for vertical ascent in shaft ready for transportation (left) and connecting horizontal pipe elements with shaft elements (right).

Case 3, prefabrication partially levels workload

The case was a new hospital building developed using the collaborative alliance model in Finland. The use of prefabricated ventilation shafts was considered separately in two project phases. The decision to prefabricate was the result of a process where costs and non-monetary factors were evaluated between on-site construction and prefabrication. The cost analysis consisted of direct costs and indirect costs (i.e., improved safety). The uncertainty related to estimating cost savings from improved safety was acknowledged by the interviewees. In addition to costs, non-monetary benefits such as the leveling of resourcing were included in the consideration. The project used takt production in the interior works phase, and shafts are traditionally constructed parallel to interior works. The interviewees noted that using takt production reduces flexibility in resource allocation and therefore favored moving non-takt-scheduled tasks off site. Additionally, the cleanliness requirement for ventilation installations was seen to favor prefabrication. The shafts would have to be cleaned and sealed off from their surroundings to preserve cleanliness. By prefabricating the ducting, these cleanings and temporary isolations were not needed. The contractor had previous experience of using prefabricated shaft elements with the same supplier. For these reasons, it was decided to use prefabrication for project phase A.

For project phase B, the same procedure was used in the decision-making process. The prefabrication of the two phases was separately bid, and the second bid turned out more expensive than the first. This was seen to favor on-site installation. Additionally, project phase A was longer in duration and therefore determined the duration of the entire project. Using prefabrication in phase B would not reduce the project's cycle time because it was not on the critical path. For these reasons, on-site installation was chosen for project phase B. It is noteworthy that project phase B also used takt production for the interior works.

While reducing cycle times or gaining schedule certainty were reported as supporting factors for choosing prefabrication, fixed site costs were not considered in the cost comparison between on-site and prefabrication. These fixed costs turned out to be significant compared to the cost of prefabrication. Being able to focus on takt-scheduled interior works without having to build the shafts at the same time was given as the main reason for choosing to prefabricate.

Designing for prefabrication was divided between the HVAC designer (engineer) and the prefabrication contractor. The HVAC designer provided the contractor with preliminary designs mainly consisting of the needed amount and size of ducts. The contractor then drafted detailed designs in collaboration with the HVAC designer and the steel frame provider. Assemblies were divided into modules that were then transported to site and installed parallel with the building frame, one- to two-story-high modules at a time. Installation during framework erection drove the early need for information from the HVAC designer.

The prefabricated shaft included vertical ventilation ducts and a steel frame that supported these ducts. The steel frame included service platforms on all floors to allow for maintenance and inspection. Additionally, the shaft elements also included heating and water pipes for temporary use during the construction.

A second interview, after the interior works had started, revealed deficiencies in the prefabricated elements. The deficiencies were issues that could have been considered in the design to eliminate the need for on-site work. An additional elevated service deck had to be built into the shafts for maintenance of fire dampers located on the inside of the shafts. Sprinkler systems had to be installed in the shafts. The maintenance deck and sprinkler system could have been included in the prefabrication. The early installation of shafts meant that designers had not yet determined the need for these systems. The locations of fire dampers were not decided at that time.

Case 4, prefabrication shortens cycle times

The case was a renovation project converting an old building in Finland from office use to hotel use. Prefabrication was chosen to keep up with a tight schedule by moving tasks away from site and distributing them to multiple contractors. The idea of using prefabrication had come up in a discussion with a designer from an adjacent construction site. A prefabrication contractor was tasked to develop a mockup design (Figure 10) for one bathroom in collaboration with the design team. The purpose of creating a mockup design was to determine the technical and economic viability of the prefabricated solution. Based on the technical and economic viability of the mockup design, estimated schedule certainty, and leveling of resources, the decision was made to prefabricate the technical shafts.

The decision to prefabricate affected the HVAC design significantly. The locations of shafts had been determined, and the design was mostly finished. Using prefabrication caused changes to the locations of shafts and required a higher level of detail in the designs in accordance with the mockup design. The HVAC design manager estimated 400–600 hours of additional design work caused by the decision to prefabricate. All the designing was done by the project’s original HVAC designer in collaboration with the prefabrication contractor. The prefabrication contractor was responsible for manufacturing and installation of the elements.

The existing inaccurate building frame caused challenges for using prefabrication. There was significant variation in the geometry of structures between rooms. The varying story height was one of the most important factors to consider. This variability was overcome by laser scanning all rooms and updating the designs accordingly for each floor and each room.

Shortening cycle times and leveling resources were given as the reasons for choosing to prefabricate. The interviewees reported having reached these goals. Prefabrication was seen as beneficial for the project even though it caused significant extra costs such as detailed design work and laser measurements.

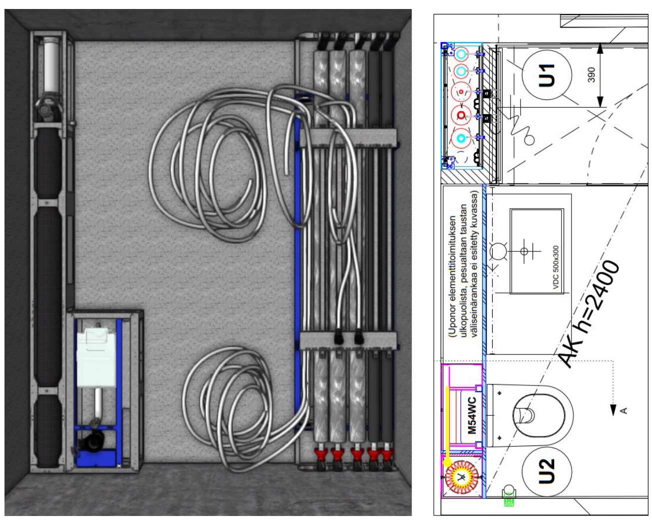


Figure 10: Mockup design of prefabricated shaft elements.

Case 5, late consideration prevents application

The case was a large new hospital construction in Sweden. The MEP contractor had previous experience in prefabrication and was therefore interested in applying prefabrication for shafts and corridor installations. The benefits of prefabrication were seen to be shorter cycle times and cost savings. During the tendering phase, the MEP contractor drafted model drawings for prefabricating corridor installations with ventilation systems, heating, cooling, water, and medical gas systems. This design was done in co-operation with a separate design consultant. During the tendering phase, the MEP designing was ongoing. When the contractor was hired, the design was already in an advanced phase and construction was to start soon. Subsequently, prefabrication was abandoned and focus shifted to improving the buildability of the designs. A prefabrication design would have required significant rework, and the time remaining before construction was too short for these changes.

Cross-case Analysis

Three of the Cases (2, 3, 4) chose to prefabricate and three (1, 3, 5) chose to build on site. Case 3 was an example of both, since different decisions were made for the two project phases. The key differences in reasons for choosing and not choosing to prefabricate along with the relative time of decision making are presented in Table 6.

The complexity of prefabrication varied significantly in the studied cases. Case 2 represented the most advanced application. The contractor in Case 2 carried out both detailed designing and manufacturing in house and used prefabrication extensively in the apartment renovation projects. All other cases had to rely on separate designers and contractors to deliver detailed designs and prefabricated products. In these cases, the use of prefabrication was centered around using one specific type of prefabricated product, such as a shaft element.

The time of consideration is a significant variable in deciding to prefabricate. Late contractor involvement in Case 5 prevented prefabrication since the design was advanced and construction was scheduled to begin. In Case 2, designs had to be completely redrawn for prefabrication, but this was done before the start of construction. In Case 3, prefabrication was considered early in the project and the HVAC designer had to be hurried on the shaft design to keep up with the prefabrication schedule. In Case 4, the design was in an advanced state and significant changes had to be made due to prefabricating, causing substantial costs. Significant remodeling in Case 5 would have resulted in large costs and might have negatively affected the design schedule. While in Case 4 prefabricating also caused redesign work and costs, the scope of prefabrication in Case 5 would have been much more complex. Nevertheless, Cases 2 and 4 suggest that investing in redesign pays off in reduced cycle times, suggesting that Case 5 might also have eventually benefited from prefabrication. The relative time of decision-making between the studied cases is presented in Table 5.

Prefabrication shortens cycle times and levels workloads. This can be a motivator for shortening individual projects duration or increasing throughput of a business unit. Case 2 wanted to shorten cycle times to be able to renovate more apartments, thereby increasing portfolio flow. To achieve this goal, it was necessary to shorten takt times, which in turn was not possible without prefabricating. Case 4 also used takt production and used prefabrication for shortening the project duration to meet the schedule. Their approach was to use a predefined shaft product for removing tasks from the site, thereby reducing the overall project duration. Similarly to Case 4, Case 3 also used a ventilation shaft product from a separate supplier to remove tasks from site. However, in contrast to Case 3, they had previous experience with the same supplier. The reasons for prefabricating were given as leveling of the workload during takt-scheduled interior works and reducing the project's duration. Cases 3 and 4 used products by a separate supplier, while Case 2 did the prefabricating and designing themselves.

Renovation project type poses difficulties for using prefabrication, as there is more variation from existing structures, but simultaneously might favor the use of prefabrication as users of the building prefer shorter construction times. Two of the three prefabricating cases were renovation projects. Renovations can be argued to be more difficult in terms of dimensional accuracy of prefabrication. Old installations and structures have greater variation compared to new structures, and this variation must be addressed in the production. Conversely, renovation projects already have a purpose, and the owners typically prefer faster construction, favoring the use of prefabrication. In apartment renovations, the owners move away for the duration of the renovation causing additional costs and other disadvantages, and in commercial buildings the renovation disrupts positive cash flow.

DfMA was consistently recognized as a prerequisite for successful prefabrication. Notably, traditional engineering designers did not take responsibility for DfMA in any of the cases. Instead, this task was typically handled by specialized prefabrication providers. In one case, the MEP designer worked in close cooperation with the prefabrication supplier to adapt the design model for manufacturing, but even this fell short of full DfMA ownership. The only case in which a general contractor assumed direct responsibility for DfMA involved in-house design and production capabilities. In the cases where prefabrication was ultimately not adopted, available documentation suggests that DfMA would have similarly required collaboration between the engineering designer and an external specialist.

In addition to DfMA, efficiently carrying out prefabrication adoption will require accurate scheduling, reliable control of schedule, advanced site logistics, and detailed understanding of methods and materials. If these preconditions do not exist before prefabrication implementation, it is likely that experiences will be negative, and the intended benefits might not be achieved. Conversely, having these preconditions in place both makes it more likely that prefabrication is considered and increases the probability of achieving the intended benefits.

Using predefined products is a feasible first step towards advanced adoption of prefabrication. In the long run, however, outsourcing knowledge about DfMA, manufacturing and installation to multiple specialized subcontractors is not feasible. The general contractor and the designers working for the general contractor must develop capabilities for adopting prefabrication without specialist contractors. The installation work itself does not change much; it is moved away from the site. What changes is managing the work, managing the materials, and managing the schedule.

It is evident that DfMA is needed for prefabrication and scheduling the design work is a crucial topic for consideration in decision making. Designing takes longer in prefabrication projects. Making the decision to prefabricate earlier can diminish the additional design time needed. This is possible since designers currently use significant share of their working time

Table 6: Cross-case analysis.

	Case 1	Case 2	Case 3	Case 4	Case 5
Prefabrication	No	Yes	Yes / No	Yes	No
Scope of prefabrication	Ventilation shaft and door frame	Multiple systems and suspended ceiling	Ventilation shafts	Risers and toilet installation	Corridor elements
Project type	New construction of a school building	Renovation of an apartment building	New construction of an hospital building	Renovation and hotel conversion	New construction of an hospital building
Main aim of prefabrication	Potential cost saving	Shortening cycle times by reducing takt time without changing work package content	To level workload, shorten duration, and achieve schedule certainty.	To shorten cycle times and level workload.	Shortening schedule
Takt	No	Yes	Yes	Yes	No
Experience in prefabrication	No	Yes. Previous similar projects.	Yes. Same shaft supplier in one project.	No	Yes. From residential buildings.
Observed costs	Direct cost estimated higher in prefabrication alternatives	Additional cost of DfMA. Prefabrication cost estimated same or lower compared to on-site.	Estimated to be more expensive than on-site construction. Cost of prefabrication increased for second phase.	Significant cost from redesign and DfMA	N/A
Observed indirect benefits	Better safety and lower material waste estimated to be benefits of prefabrication	Less material waste. Improved quality. Efficient methods in workshop.	Easier dust control during interior work, less cleaning. Less working in elevated positions.	Reduces on site work	N/A
DfMA	Need for DfMA was recognized but it was not clear who would have been responsible.	DfMA designer employed by GC	DfMA by the prefabrication provider	DfMA design in collaboration with MEP engineer and prefab provider	DfMA was discussed with a separate design consultant
Enablers	Emphasis on safety and reducing material waste	Takt production and logistics, separation of materials and work. Costs and benefits equal when GC is responsible for DfMA and prefabrication.	Accurate scheduling to show the benefits, previous collaboration with the supplier, predefined product from a supplier	Accurate scheduling to show the benefits. Need to shorten schedule. Supplier with a predefined product.	Collaboration with DfMA consultant. Early contractor involvement would have been an enabler.
Obstacles	No capabilities for DfMA, logistics, manufacturing. Obstacles are overemphasized when cost benefit is not expected. It is difficult to estimate cost savings from enablers.	Inaccuracies in old buildings. Achieving benefits required changing scheduling. The detailed design barrier was overcome by developing skills.	Increased cost of prefabrication. Overlap between design and construction was an obstacle for DfMA. Benefits of prefabrication can only be realized on the critical path.	Revising MEP designs	Separating designing from construction limits the contractors influence on optimizing work. Major redesigning was needed and construction schedule did not allow for this.
Relative time of decision	4. Structural work started	1. Construction not started	2. Groundwork started	3. Demolition started	5. Structural work started

for BIM coordination that must be redone in DfMA phase. Removing this overlap requires an early decision to prefabricate. However, when comparing the additional costs of DfMA to its potential benefits, it is important to recognize that in traditional construction, installation design is typically outsourced to installers. Prefabrication eliminates the need for this on-site design work, thereby reducing overall construction costs.

Successful adoption of prefabrication requires acknowledging advantages, overcoming obstacles, and financial feasibility. Acknowledging advantages provides a foundation for changing behavior. The obstacles must be acknowledged to overcome them. Finally, the advantages must translate into profitable business at the project or company level. Conversely, adoption of prefabrication will likely fail if benefits are not acknowledged, obstacles are not overcome, or prefabricating is not financially feasible. Not knowing why prefabrication is chosen means there is no commitment to implementation. Obstacles become barriers when they are not recognized beforehand and tackled. Even with commitment to achieving benefits and overcoming obstacles, prefabrication is not a sustainable business if it compromises the profit. The adoption of prefabrication introduces additional costs, particularly for DfMA and manufacturing, which must be offset by clear project-level or company-level benefits. Without recognized advantages or organizational readiness, adoption is unlikely to succeed.

Reasons for not prefabricating were more diverse compared to those for prefabricating. In Case 1, higher direct costs were quoted as the primary reason for not prefabricating. In Case 3, for project phase B there were two reasons given: the increased direct cost of prefabricating compared to phase A, and less benefits as phase B was not on the critical path. In Case 5, the reason given was late contractor involvement and the subsequent need for rapid and extensive redesigning for prefabrication to be feasible.

Using prefabrication to achieve a valued goal drives its adoption. In many cases this goal was shortening cycle times but, similarly, improved quality, improving flow, and gaining schedule certainty were mentioned. The role of takt production was emphasized in all prefabricating cases. Takt production is a tool with similar benefits to prefabrication and combining them seems to increase the desired effects. In Cases 2 and 4, takt production was employed first, and after removing slack from the construction site the next step to shorten cycle times was to transfer tasks away from site.

In addition to differences in motivations guiding decision-making, differences can be found in the farsightedness of decisions. While decisions are always made on a project basis, long-term project to project thinking might favor prefabrication more. In Case 1, prefabrication was a result of a long lean implementation, and in Case 3, the contractor had previous experience with the same prefabrication contractor and the same type of shaft element. One company deploying the same system across projects enables continuous improvement and the seamless transfer of information between projects. This is in contrast with temporary project organizations that are unable to transfer knowledge between projects.

While developing capabilities for prefabricating carries costs, so does unwillingness to develop new practices. Case 1 cited direct costs and the necessity to win cost-based bids as the primary reason for choosing not to prefabricate. The long development process in Case 2 significantly improved the production rate. In Case 3, previous experience with a prefabricating contractor resulted in a reduced project duration, and in Case 4, accepting higher direct costs meant that a tight schedule could be achieved and the customer could start using the building for generating revenue earlier. If some companies make these investments, traditional methods might not be enough to win future bidding competitions.

Discussion

The purpose of this study was to determine the differences in decision-making processes leading to different outcomes in choosing or not choosing to prefabricate. The study has three main results. First, the results indicate that decision-making processes differ between projects; some used project-specific consideration and some strategic long-term consideration. Second, all the prefabricating cases cited shortening cycle times as a contributing factor. Third, the results disprove the existence of barriers for the adoption of MEP prefabrication. In the following analysis, we discuss these three main results in detail.

The decisions can be divided into two categories: long-term decisions and project-specific decisions. In the first, the decision regarding the use of prefabrication has been made as a strategic decision at the business unit level and remains the same going from project to project. In the second, decisions are made for each project or even each project phase, and the outcome depends on many variables. The first type of decision is made possible by constant vertically integrated project organization, removing the need for information exchange over the project's event horizon. In the second type of decision, late consideration has a negative effect, as reported by previous research (Hall et al. 2018; Lavikka et al. 2021). Additionally, the use of a predefined product (such as a shaft element) and previous experience with the product favors choosing to prefabricate. In both long-term and project-specific decisions, the shortening of cycle times was identified as a major reason for prefabricating.

Shortening cycle times can be beneficial from many points of view. It can be a way for a company to generate more revenue and profit by completing more projects in the same timeframe, or it can shorten the duration of a single project. Shortening cycle times carries cost benefits. Finishing earlier can save significant fixed costs of running a construction site. For a client, shorter cycle times may be desirable regardless of the increased cost of construction. In apartment renovation projects, the owners must rent a second apartment for the duration of the renovation. In commercial buildings, revenue is lost during the renovation. Combining takt production with prefabrication is beneficial and this has been previously suggested (Chauhan et al. 2018). We argue that there are two reasons for this. First, citing the shortening of cycle times as a reason for choosing to prefabricate requires detailed schedule knowledge to determine that prefabrication is being applied on the critical path and to determine the magnitude of possible time saving. Second, using takt production means that the low-hanging fruits for compressing the schedule have already been picked, and further reduction requires moving tasks away from site. This implies that takt production can stand on its own but that prefabrication is more beneficial when built on takt production.

The effect of combining takt planning and prefabrication has been studied by Chauhan et al. (2018). Their study compared two projects: one combining takt planning and prefabrication, and another implementing takt without prefabrication. In the first case, takt planning was introduced independently, and it was later observed that trades already employing prefabrication benefitted from the structured workflow and predictable batch sizes provided by the takt schedule. There is no indication that either practice initiated the other; rather, their coexistence appears to have been coincidental. In the second case, the development of a takt schedule led to the realization that further cycle time reduction would require the introduction of prefabrication, a benefit that had not been evident before. This suggests that takt planning may act as a catalyst for prefabrication by making its advantages more visible in the context of synchronized production. Our results reflect a similar pattern, where prefabrication appears to have followed takt planning rather than preceded or initiated it. While it is possible that prefabrication could, in some cases, motivate the adoption of takt or other advanced scheduling practices, such bottom-up influence seems less common. One potential explanation is that prefabrication is typically initiated by subcontractors, whereas takt planning and other scheduling strategies are managed at the general contractor or client level. This structural distinction supports the hypothesis that top-down planning mechanisms are more likely to enable or amplify subcontractor-led process innovations than to be initiated by them.

The research literature has identified a number of barriers to MEP prefabrication (Lavikka et al. 2021). The studied cases show that all these barriers can be overcome, as shown in Table 7. We conclude that instead of barriers, these are obstacles or even excuses; they slow down movement toward prefabrication but do not prevent it.

Adopting or not adopting MEP prefabrication does not seem to be dependent on technical or political barriers. Instead, the obstacles were seen to be project- and cost-related. The cases show that to prefabricate requires overcoming obstacles caused by the traditional way of building, such as the requirement for detailed design, early design freezes, and partial optimization by bidding the cheapest subcontractor. While these obstacles were discussed, especially in Case 1, they were not seen as the main deciding criteria. Instead, direct costs and schedule considerations were the main deciding criteria. “Re-mirroring,” as described by Hall et al. (2019), allows for the fair distribution of costs and the resulting benefits and seems to contribute to the adoption of prefabrication. Collaborative contracts and vertically integrated companies are examples of “mirror breaking” and subsequent “re-mirroring”.

DfMA is an important topic for consideration in adopting prefabrication. The results confirm the need for separate DfMA (Lavikka et al., 2021), and it can require significant design time (Dodge, 2020), influencing the project’s schedule. This additional time partly influences the need for an early prefabrication decision. Additionally, the need for DfMA combined with the fact that engineering designers often do not have the capabilities to deliver DfMA necessitates early contractor involvement either to support the design or to provide the

Table 7. Findings from cases compared to previously identified barriers of prefabricating.

Barriers to adopting prefabrication (Li et al., 2017; Dodge et al., 2020; Lavikka et al., 2021; Zhang et al., 2022; Lopez et al., 2022)	Findings from cases
Few prefabrication solution providers	Prefabrication providers exist. Separate providers are not necessarily needed for prefabricating.
Lack of knowledge about the timing of freezing the design Design revisions prevent prefabrication	Late contractor involvement prevents prefabrication. Design changes in detailed design phase are expensive.
Lack of prefabrication procurement knowledge	Previous experience favors future use cases. Outsourced products don't require previous experience.
Price as the main bidding criterion	Without other lean adoptions and considering only direct costs, this is a barrier. However, Case 2 prefabricates and wins contracts in the extremely competitive apartment renovation market.
Used to designing one-of-a-kind products Lack of repeatability in designs Lack of installation-level designs	Separate designing for prefabrication is required. Repeatability is beneficial but not necessary.
Industry's resistance to change Risk-averse culture Business models, contract boundaries	Collaborative delivery methods and untraditional contracting were observed in prefabricating cases.
Lack of capabilities for detailed design	MEP designers seem to lack the capabilities for detailed design, but specific detailers have these capabilities.
Tight schedule	Having a tight schedule was identified as both an obstacle and an enabler for prefabricating. It might mean that there is no time for detailed design or, conversely, that by paying for detailed design, construction time can be shortened.
No shared implementation strategy	Single contractor has limited influence. Late contracting and inability to leverage the schedule prevented prefabrication.
Union agreements for prefabrication payments	Not quoted in any of the cases.
The market is missing for prefabricated products	The findings indicate that a market exists. The size of the market cannot be determined based on the results.
Project type not applicable for prefabrication	Not quoted in any of the cases. The list of possible use cases created in Case 1 suggests that some level of prefabrication is possible in all or most project types.
A lack of local prefabrication shop and trained workforce for installation	Lack of prefabrication shop was considered as an obstacle in Case 1. Case 2 indicates that a separate shop is not necessarily needed, the installers can make the assemblies without a specialist shop. Lack of trained workforce was not quoted in any of the cases.
Increased logistics considerations, transportation, lifting, protection, storage, site access.	Increased demands for logistics as an obstacle is supported by the findings. Case 1 considered these as part of the evaluation. Case 2 had previously implemented advanced takt logistics enabling efficient prefabrication. Cases 3 and 4 also highlighted the need for logistics considerations especially lifting capacity during the frame erection.

detailed design. Yuan et al. (2018) show the required detail for concrete elements and Court (2019) does so for MEP prefabrication; these findings are confirmed by the results of this paper.

Comparing prefabrication in concrete elements and in MEP reveals differences in designing for prefabrication. In both cases the manufacturer of the prefabricated elements is responsible for production design. For concrete elements the structural engineer can produce element drawings with correct dimensions and required amount of rebar. A design for prefabricated concrete beam does not differ from a design for a cast in place beam. For MEP the difference is much clearer. The MEP designer provides a more schematic design that describes the installation with lower level of accuracy and leaves certain details to be resolved on site. Resolving all these details, such as all the actual products and hanger systems, requires a significant increase in model detail and subsequently in design time, as suggested by the results. This means that purchasing MEP prefabrication services makes the owner or general contractor overly reliant on the provider, as the DfMA cannot be made by the MEP designer, and bidding becomes product centered and includes services that others cannot provide. Bidding prefabrication with DfMA by the MEP designer likely would benefit the project since there would be more competition.

While the projects were of different types, four out of five companies operate in the same Finnish market and compete for projects in a market where contracts are won or lost based on cost. The cases have differences in design schedules. Apartment renovations are bid on ready-made construction drawings. In larger projects, designing is more concurrent with construction. This difference becomes less significant with the observation that construction drawings for bidding must be completely redesigned for prefabrication, eventually causing similar concurrency as in larger projects.

What can be learned and generalized to non-MEP construction? The often-cited benefits of prefabrication may not align with a project's specific priorities. Therefore, the decision should shift from pursuing generic benefits to evaluating project-specific needs and determining whether prefabrication supports them. It is noteworthy that prefabrication should not be the first initiative to implement or the only transformation to consider. In fact, the results indicate that prefabrication might best serve the project when other lean transformations have already been carried out. Adopting prefabrication requires a mature production system capable of detailed planning, scheduling, and coordination, elements often absent in traditional project setups.

A significant shortcoming in discussing prefabrication is incomplete question framing, causing an overemphasis on the prefabrication itself when prefabrication cannot exist or be considered in isolation. It is always connected to a specific project with unique characteristics and is always accompanied by changes to the traditional production system. Prefabrication consideration requires systems thinking all the way from design to installation. Based on our findings, similarly to O'Gorman et al. (2023), we suggest that only considering MEP prefabrication and the direct costs related to it is not recommended. Contrary to O'Gorman et al. (2023), however, we argue that this is not due to a lack of cost savings from prefabrication but to incomplete question framing, where prefabrication is considered alone without all the other necessary transformations toward industrial construction. The only way for prefabrication to succeed is to implement and improve it over time as part of other methods of industrial construction. Simply considering the non-monetary aspects is not feasible when contracts are won or lost based on cost only.

This study is limited by the low number of cases, which limits the reliability of the drawn conclusions. Additionally, these cases represent the situation in the predominantly non-prefabricating Finnish market, and differences could be found from countries of advanced application. Further investigations involving a larger number of cases in other markets are needed to confirm the results and determine how project type affects the decision-making process. Considering the long history of prefabrication, its current relatively low adoption rate, and recent failures of large modular constructors, it would be interesting to conduct a longitudinal study determining the reasons for prefabricating, the fulfilment of original motivators, and the long-term survival of the method, as opposed to the current focus on single use cases and projects.

Conclusions

In this paper, we set out to determine why some projects prefabricate while others do not. We studied five cases and determined the reasons for choosing or not choosing to prefabricate and details regarding the prefabrication and related processes. Out of the five cases under study, two chose to prefabricate, two chose to build on site, and one chose differently for two project phases. The reasons cited for not prefabricating were the instrumental use of prefabrication as the only lean method to gain direct cost savings, the inability to reduce cycle times on a project phase that was not on the critical path, and late contractor involvement. All the prefabricating cases cited shortening cycle times as a reason for prefabricating. The motivation to shorten cycle times was to complete more projects and to achieve tight schedules. Leveling workload and improving flow and quality were also cited as reasons to prefabricate. The use of takt production was common for all prefabrication projects.

The results imply that “to prefabricate or not” might not be the right question. A more appropriate question is connected to solving a problem that is related to a specific project or a strategic goal of a company and determining whether prefabrication might be the answer. It is noteworthy that prefabricating might not be the first solution to achieving goals. None of the prefabricating cases focused on the difference in direct costs compared to on-site construction; instead, cost benefits were seen in terms of the bigger picture or cost was not a deciding factor.

Prefabrication is envisioned to transform the construction industry by moving from craft production to industrial production. There are brilliant examples of successful prefabricating projects and companies suggesting that the method is feasible. However, at the same time, failures of large modular builders are and have been in the news. The results of this study detail the reasons for and against prefabricating in five MEP cases, offering concrete examples as a foundation for decision-making in future projects. To conclude, prefabrication is not a panacea to strap onto an otherwise broken project structure but, when administered correctly to address a specific issue, it can prove helpful.

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