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International Journal of Construction Management

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tjcm20

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To cite this article: Mark van der Ham & Raymond Opdenakker (2023) Overcoming process-related barriers in modular high-rise building projects, International Journal of Construction Management, 23:10, 1779-1789, DOI: 10.1080/15623599.2021.2007593

To link to this article: https://doi.org/10.1080/15623599.2021.2007593

INTERNATIONAL JOURNAL OF CONSTRUCTION MANAGEMENT
2023, VOL. 23, NO. 10, 1779–1789
https://doi.org/10.1080/15623599.2021.2007593

Overcoming process-related barriers in modular high-rise building projects

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ABSTRACT

Modular projects can be of higher quality, a safer, faster and more predictable construction process, and less environmental nuisance compared to a traditional on-site project. High-rise projects seem to be particularly suitable for modular building methods, however there are still some process-related barriers. Research so far has not focussed on collaboration forms for modular high-rise projects. This paper examines which collaboration form fits best for a modular high-rise project by conducting an international case study research. From the case studies it is debatable whether the current PDMs meet the need for modular concepts; modular buildings will benefit more from a long-term collaboration with fixed partnerships. This requires a complete different approach to the construction industry. Until then, the best match should be sought by matching the customer profile to the PDM characteristics. The most suitable PDM is dependent on the client profile that can be determined by 17 selection criteria.

KEYWORDS

Modular construction; modular building methods; modular high rise; product modularity; collaboration forms; project delivery model

Introduction

The ever-growing urbanization demands a strong need for high-rise projects in the city. Smaller construction sites and stricter regulations in an urban environment require different construction methods. A development that potentially can solve the problem of the growing need for housing in inner cities is the industrializing of construction methods. A good design practice of high-rise buildings is to embrace simplicity, standardization, repetition, and economy of scale. This renders the high-rise buildings to be intrinsically modular by off-site factory production (Jonsson and Rudberg 2014; Liew et al. 2019).

Modular buildings consist of off-site factory-made components, parts, pieces and sub-assemblies (called modules) that are transported and assembled on-site to become part of a larger, primary building project. They may represent a small portion of the project or form an entire building (Ferdous et al. 2019; Kobet 2009). Modular building methods potentially have major advantages on improved quality and accuracy in the manufacture, economy of scale in the manufacturing of multiple repeated units, the speed of installation on-site, improved safety and health on-site, and reduced environmental site disturbance (Aitchison 2018; Choi et al. 2019; Wai et al. 2021).

Despite all these advantages, modular building is not yet a common construction method in high-rise projects. Several studies have researched the past and current barriers to implementing prefab modular housing (Ferdous et al. 2019; Jabar et al. 2013). Of these identified barriers several issues involve process-related barriers of modular building, such as lack of integration of the project team, lack of cooperation between contractors, and communication issues. A successful path to modular prefabrication is one of collaboration, which requires teamwork and a broad set of complementary skills and knowledge (Jonsson and Rudberg 2014). Modularization is a strong concept that explains not only the architecture of products but also the organizations and processes for designing and producing them (Peltokorpi et al. 2018).

A great deal of academic research into modularity in the construction world has been carried out, but research into forms of collaboration within modular construction is still lacking. Thus the aim of this research is to present a framework in which forms of collaboration can be organized to overcome the process-related barriers of modular high-rise projects. In developing the framework, the following research question is addressed: *How should collaboration forms within a prefabricated modular high-rise projects be organized in such a way that the current process-related barriers can be overcome?*

This paper is divided into two phases. The first phase focuses on developing a theoretical framework that is built in order to overcome the current process-related barriers based on the available literature. Here, the conditions for prefabricated modular building methods will be weighed against the variables of collaboration that can help to overcome the current process-related barriers. Then, in the paragraph concerning 'data and methods', data collection and data analysis will be described. In the second phase, the verification of the theorical framework is central. By conducting a multiple holistic case study, consisting of three cases, the theoretical framework was empirically tested. In the 'Results' paragraph, three cases compare the theoretical concepts of modularity and collaboration forms with experiences how it is dealt in practice. In the end, conclusions and discussion are presented.

Framework

Within the theoretical framework two research topics are integrated, modular building methods and collaboration forms in construction industry.

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Characteristics modular building in high-rise projects

For decades, the construction industry is searching for ways to improve productivity. Mass customization is seen as one of the strategies to improve productivity. The central idea of mass customization is the paradox of delivering products that have some degree of customization while striving to meet the standards of efficiency, cost, and quality of mass production (Niemeijer 2011; Rocha et al. 2015). Modularity is one of the key elements of mass customization strategies. It concerns the use of a limited set of modules to create several product variants which allows efficient production. Modularity in the construction industry is about dividing a building into treatable standardized parts and shifts many aspects of building activity away from traditional onsite projects to offsite manufacturing-style production. All modular buildings are prefab, but not all prefabs are modular.

Research into industrialized building concepts and other modular industries discuss that not every project is suitable for modular building concepts: If a customer requires an extra special architecture, we are talking about 'haute couture' and this requires an individualized project-based building process. Modular buildings are ideally suited for cellular-type buildings, such as hotels, student housing, prisons; buildings with a lot of repetition (Hough and Lawson 2019). The promising benefits of higher quality, a safer, faster and more predictable construction process, and less environmental nuisance could be one of the main drivers for the realization of a modular high-rise project. High-rise projects seem to be particularly suitable for modular building methods due to the naturally present repetition and standardization in the design (Jonsson and Rudberg 2014; Generalova et al. 2016; Liew et al. 2019; Thai et al. 2020). Modularization is a strong concept that explains not only the architecture of products but also the organizations and processes for designing and producing them (Peltokorpi et al. 2018).

Modular building methods require a different project planning compared to other building methods. An extensive pre-engineering at an early phase of the project is required in order to come to an 'early design freeze' (Gao et al. 2018; Wuni et al. 2020). To reach this collaboration between all stakeholders should be the basis from the start.

Process-related barriers for prefabricated modular high-rise projects

Many of the challenges that modular construction method entails have been known for more than 20 years. The points of attention that were mentioned at that time are still seen as a barrier. Besides generic barriers, such as, high initial investment, lack of awareness and the comparison to temporary buildings associated with low quality, the current culture of the construction industry is a major hindrance in the implementation of modular building methods.

Conventional projects are demand driven rather than the result of arm-length market transactions, which typify product-driven industries. Prefabricated modular construction solutions require a process-based approach that goes beyond the life of any building or project. Project-based working is typical of a conventional building. This makes the development of an industrialized modular concept within the current project-based construction industry paradoxically.

Even in the area of process-related barriers studies have been known to identify these barriers. For example, there must be a more frequent and intensive collaboration with all stakeholders involved, throughout the entire process. To prevent information loss after every construction phase, when information is sent from one party to another, there must be a multidisciplinary integrated process (Hwang et al. 2018). A process in which all parties work together in all phases of the process. For example, during the design of a module, the conditions that the manufacturer sets to be able to produce the module must already be taken into account (Wuni et al. 2019). One way to achieve this is by assigning a larger and more determining role of the manufacturer during the design phase. Managing this process is seen as the biggest process-related barrier to modular construction. Blismas et al. (2005) state that more collaboration, with more parties, requires effective open communication from all stakeholders involved. Effective communication is needed to make key decisions that must be taken early in the process. The planning in a modular construction project is critical because the manufacturer already starts producing the end product before the construction site is already finished. This requires making early key decisions, which is experienced as difficult. The customer or the designer is often not able to freeze the design and specification early enough within the construction project process (Wuni et al. 2019; 2020).

Main characteristics of collaboration forms

Collaboration within the construction industry centres about the development of a building. The client can choose between doing everything himself or tendering out some works. To steer this in the right direction, it is important that mutual relationships between the project partners are clear (Wamelink et al. 2010).

Clients need to make an informed decision for a collaboration form, given that it largely determines the future process and end product. What this well-considered decision strongly depends on is the degree of influence by the client characteristics, project characteristics, and market environment at that moment. A Project delivery model (PDM) is a system for organizing and financing the design, construction, operation and maintenance activities and facilitates the delivery of a good or service (Engebø et al. 2020). Zhu et al. (2020) state that selection of an appropriate PDM is the basis of success in every construction project. Concerning construction, there are several standard most used project delivery models: Design-Bid-Built model (DBB), Early Contractor Involvement model (ECI), Design & Build model (DB), Turnkey model, Design-Build-Finance-Maintain-Operate model (DBFMO) and Partnership model. The most important difference among all the models is the way coordination and control takes place. In the DBB model, the client takes care of the coordination. The client may decide to form a team to coordinate the entire process (Building team). Early Contractor Involvement (ECI) contract literally translates to involving a contractor 'early', which in current practice implies that the contractor is involved before the design phase (Wijck 2018). In both PDM's the client remains responsible for coordination and control, which means that he is also the system architect.

When using DB the coordination is partially outsourced to a contractor. DBFMO and Turnkey PDM's fully outsource the coordination. In these three PDM's the market parties decide upon the design rules and thus are the system architect. Besides these options, the client could also form a new partnership with a contractor and both are equally responsible for coordination (Wolters 2002).

Variables of collaboration to overcome current process-related barriers

Each of the PDM models described has its own characteristics, advantages and disadvantage with the best choice being governed by the requirements of the specific project. Often the choice for a PDM is based on experiences in previous projects. Based on the research of Hosseini et al. (2015) seventeen selection criteria are used to make a significant distinction in the characteristics of the various PDMs (see Table 1). According to the researchers the selection of a suitable PDM entails two main steps: identification and formulation of the project selection criteria, and the evaluation of the different PDM strengths and weaknesses against the PDM selection criteria.

In order to be able to compare the PDMs with each other a value of 1 to 4 was given to the selection criteria, see Tables 2 and 3. The ranking is done through Simple Multi-Attributing Rating Technique where a scale qualitative effects score is used, as described in Hombergen et al. (2004). When giving scores, the emphasis is on comparing: it is not about saying per PDM 'this is good' or 'this is bad', but to present the different alternatives side by side so that a comparison based on different selection criteria is promoted. To make the most suitable PDM choice, a client profile should be made using the seventeen selection criteria. The client profile is based on his specific requirements and wishes. The scores of the client profile can be compared by means of a spider chart with the scores of the PDMS. Based on the in-depth interviews, a customer profile was created for each case in the case study, which was then compared with the profile of the chosen PDM.

Methods

To empirically test the theoretical framework, we have chosen to use a multiple holistic case study. In the first place, a case study, as in this case concerning 'collaboration forms within a prefabricated modular high-rise project', lends itself well to study a phenomenon that has not been extensively researched yet and for which there are no clear frameworks in the literature (Yin 2018). In the second place it also gives the opportunity to investigate the phenomenon in a real-life setting (Yin 2018). In the third place a case study research leads to rich, empirical descriptions and information that can contribute to the development of theory (Saunders et al. 2019). Yin (2018) state that when there is only one concept presented within the Theoretical Framework, two to three cases would cover the literal replication. To assess whether a case is suitable for this research, it must meet several case study selection criteria:

1. A modular construction method must be applied in a certain way.
2. The building must represent a certain degree of a high-rise. Here, we use the definition of a high-rise building taken over from the Dutch construction knowledge institution SBRCURnet (2014): 'A building with a user area floor higher than 70 meters above the measuring level is considered high-rise buildings (…).'
3. Another criterion for the case selection is that the cases must be completed or should be at least in the construction phase. This is relevant because then the client and contractor have collaborated during the design phase and the construction phase.
4. Also important in the selection of the case studies is the number of perspectives. There must be several perspectives to get a complete picture of the cases. Both designing parties and implementing parties must, therefore, be prepared to participate.

Three different cases were investigated in this case study research, which come up to the criteria: The Fizz Spartaan (Amsterdam, the Netherlands), CitizenM Bowery (New York, USA) and Mapleton Crescent SW18 (Wandsworth London, UK).

Data collection

Data for the study were gathered through semi-structured interviews with (project)managers, and (with the organization's permission) from documents such as organizational forms, collaboration policies and meeting overviews. But also project websites, project descriptions, and news items about the project were reviewed to get a deeper understanding of each of the projects. In this way, data source triangulation was met (Patton 1999). A total of 10 stakeholders were interviewed, at least 3 stakeholders per case. As the aim of the interview was to investigate to what extent the process-related barriers as identified by theory also play a role in practice, and to what extent the form of collaboration could provide an answer to this, the interviewees chosen had direct involvement with the project at management level during the design phase or execution phase of the project. The interviewee also had knowledge of the realization of the form of collaboration and associated contracts. The semi-structured interview approach allowed for flexibility with a preference for posing questions so that the interview was more like a conversation; whilst the focus was maintained on particular key issues of the research questions. These semi-structured interviews were all conducted in synchronous communication in time, either by face-to-face interviews or online conference call interviews. This has the advantage of getting familiar with social cues, such as voice, intonation and body language which provides the researchers with a lot of extra information that can be added to the verbal answer of the interviewee on a question (Opdenakker 2006) (Figure 1).

An interview protocol was used to conduct interviews and thus collect data from the cases. Based on the theory some research subjects are selected, and translated into the interview questions. The protocol is tested in test interviews and discussed with a peer in order to increase the construct validity. The protocol roughly discussed the structure of the interview procedure, the respondents' profile, permission for voice recording and research questions. Recording the semi-structured interview has the advantage that you can listen more carefully and have more interaction with the interviewee, which leads to a more natural conversation. The conclusions and transcripts were sent to the interviewees for verification, which improved the construct validity of the question list as prepared in the interview protocol.

Data analysis

After verification of the respondents, the interview transcripts were coded in Atlas.ti using coding into understandable concepts. Coding is a way of categorizing the data into concepts, properties and patterns. Within the case report, a Template analysis style is chosen to analyse the data obtained from the semi-structured, face-to-face interviews (Opdenakker 2012). A coding template has been elaborated based on the literature studied in advance. Here, the answer to the sub-question four: 'variables of collaboration to overcome process-related barriers'gave a

Table 1. Overview of most used selection criteria for choosing a project delivery model (source: adapted from (Hosseini et al. 2015)).

	Selection criteria	Description	(Hosseini et al. 2015)	(PSI Bouw 2005)	(Regieraad bouw, 2009)	(Mahdi and Alreshaid 2005)	(Kumaraswamy and Dissanayaka 1998)	(Chan C., 2007)	(Ng et al. 2002)	(Qiang et al. 2015)	(Love, Skitmore, & Earl, 1998)	(Ling and Liu 2004)
Client Characteristics												
1	Owners Available HR	Owners capability to use own resources	X	X						X		X
2	Owner willingness to be involved	Ability or desire to be involved in the project details	X			X					X	X
3	Owner willingnes to take risk	The shifting of risk from client to the contractor	X	X				X			X	
4	Dispute	Minimize claims and disputes between design and builder	X			X					X	
Project characteristics												
5	Project type	Type of project (housing, road, office)	X				X		X			
6	Project scale	Size of project (value, number of stories, floor)	X				X		X	X		X
7	Complexity	The suitability of the procurement method in handling complex project	X	X	X			X		X	X	X
8	Delivery speed	Desire to have the project completed as soon as possible	X	X					X		X	
9	Schedule delay	Degree of certainty that the project will be completed on time	X	X		X			X			X
10	Scope definability	Ability to define the project scope accurate	X			X						X
11	Flexibility	Amount of flexibility for design changes during construction process	X	X				X		X	X	X
12	Innovation	Ability to incorperate innovation into the project	X	X								
13	Quality performance	The quality level required of the completed project	X	X		X		X			X	
14	Cost certainty	The certainty over the cost for completion of the project	X	X		X	X	X			X	
15	Cost growth	Degree the final project cost can growth compared to contract project cost	X									X
External environment												
16	Contractors capability and availability	Performance of available contractors and consultants on previous (similar) projects	X	X			X			X		X
17	Market competitiveness	Status of local market, including available capacities of potential project participants, scarcity of work in particular fields	X	X			X			X		

provisional 'start list' of codes before the actual execution of the case study. On the basis of open coding, axial coding, and selective coding (Strauss and Corbin 1996), for each case a within-case analysis was elaborated. In the end, the three within-case analyses were compared in a cross-case analysis.

Ethical concerns

Withdrawal from the interview was at all times possible for the respondents, and the anonymity and confidentiality of respondent's data have been protected throughout the research process. The Dutch code of conduct for academic and scientific practice from 2018 (VSNU 2018) has been applied.

Results

Case description

Based on the above mentioned selection criteria three high-profile cases in three different countries have been selected: The Fizz Spartaan (Amsterdam), CitizenM Bowery (New York), and Mapleton Crescent SW18 (London).

The Fizz Spartaan

The project The Fizz Spartaan, located at the Laan van Spartaan in Amsterdam, The Netherlands, is currently the highest modular building project in The Netherlands. The 361 student apartments are developed by IC Netherlands and BPD gebiedsontwikkeling and are finished in the year 2017. The building is 16 levels high and consists of in total of 389 modules.

Table 2. Overview of scale with a neutral centre point (source: (Hombergen et al. 2004)).

4	Very strong effect
3	Quite a lot effect
2	Little effect
1	Very little effect
0	No effect at all

CitizenM Bowery

This 21-story hotel is developed and operated by Dutch hotel brand CitizenM, and located at 189 Bowery in Manhattan New York. CitizenM Bowery is currently the tallest modular hotel in the U.S. The building measures approximately 9300 square meters with a total of 300 guestrooms and was finished in September 2018. There are two rooms and a corridor within one module. The 210 modular steel units are prefabricated in Poland

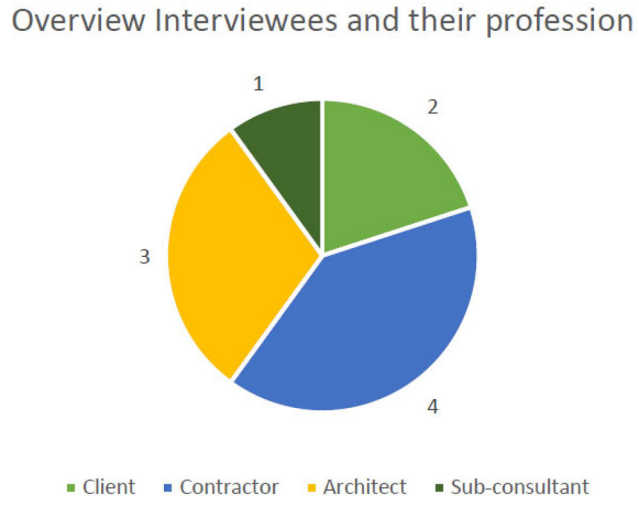

Figure 1. Pie chart of number of interviewees and their function (source: own illustration)].

Table 3. Overview of six different PDMs and their response capacity of each selection criteria given in a score of 0 to 4 (source: own illustration).

	Selection criteria ***System Architect***	Design-Bid-Built Client	Early contractor involvement Client	Design & built Contractor	Turnkey Contractor	Design-Built-Finance-Maintain-Operate Contractor	Partnership Client & Contractor
Client Characteristics							
1	Owners Available HR	4	3	2	1	2	4
2	Owner willingness to be involved	4	3	1	1	1	4
3	Owner willingnes to take risk	4	3	2	1	1	1
4	Dispute	1	2	3	4	4	4
Project characteristics							
5	Project type	0	0	0	0	4	4
6	Project scale	0	0	0	0	4	4
7	Complexity	3	2	3	1	4	4
8	Delivery speed	1	3	2	4		1
9	Schedule delay	1	3	2	3	3	4
10	Scope definability	4	3	2	4	1	1
11	Flexibility	4	3	3	1	4	4
12	Innovation	1	2	3	3	4	4
13	Quality performance	4	3	2	2	4	4
14	Cost certainty	2	2	3	4	1	1
15	Cost growth	4	2	3	1	1	1
External environment							
16	Contractors capability and availability	1	2	3	4	4	4
17	Market competitiveness	1	2	3	4	4	4

by Polcom Modular(hereafter PolCom) and shipped to New York containing most of their furniture.

Mapleton Crescent SW18

The Mapleton Crescent SW18 is with 27 levels Europe's tallest residential modular building, it is located in Wandsworth, London, UK. With its 89,2 meters The residential tower consists of 89 dwellings, 53 of which are designated by the owner Pocket Living as affordable first-time buyers, There is also 36 two and three-bedroom open market. Pocket Living helps singles and couples on low to moderate incomes to fully own a home of their own as apartments are at least 20% the market rate. The affordable one-bedroom apartments exist out of two modules and measures 38 m2 (Hough and Lawson 2019).

Case results

The Fizz Spartaan

The Fizz Spartaan was successful, the project was delivered within time and within budget. It was a project where the customer had no previous experience with modular building, the other project partners(the architect and the contractors) did. The fact that the contractor has been selected via a Turnkey PDM has to do with the characteristics of the client. IC Netherlands was initially primarily involved as an investor with Laan van Spartaan, which means that they would invest in the project and would hand it over to the actual end-user after completion. Therefore there is no need for a large involvement in the development of a modular concept. Both the willingness to be involved as the willingness to take a risk was very low. The minimal role of the client can also be explained by the fact that the client will never bear the risk for a construction method that can be specifically related to one supplier.

By opting for a Turnkey PDM, the customer also opts for a fixed budget and a fixed price. The fixed budget was also interesting for the contracting parties, because it immediately gave them clarity about possible innovations to be applied. 'Then you know where you stand and then you go all out to make something for that budget' (one of the respondents).

During the design, two different building flows run together: For example, the overall design of the building is a traditional process that involves designing from global to detailed. Furthermore, the design of a standard module is directly drawn forward in the design process. Once a standard module has been worked out, it is used by the architect to design the rest of the building. As a result, there is a leap in the detailing, where the building first comprises a roughly outline design, after the module it becomes very detailed. All respondents recognize the importance of a prototype for one module in making fast key decisions.

CitizenM bowery

The Bowery project is, in various respects, a special project, it is, the highest modular hotel in the world. In addition, the modules were built in a factory on a different continent (in Poland) as to where they were assembled (in New York). The client CitizenM believes very strongly in the realization of buildings in a modular concept. The modular idea stems from CitizenM's company mission to make better-quality projects. This is reflected in the loyalty in the hotel room concept, even though it may have cost more money than the past projects. This belief in the modular system ensured that the client took more risk than it would normally do, such as taking over the transfer of ownership.

The chosen PDM in The CitizenM Bowery project was a Design-Bid-Built organization with a clear distinction between the design and execution phase. CitizenM made with all the consultants independently a contractual agreement. The contract between those parties is a standard consultant contract. After finalizing the design phase the total project is put out to tender by the client CitizenM as is normal within a Design-Bid-Built contract. This is mainly due to the willingness to be involved by CitizenM. In addition to the conscious choice for a modular system, the client also has active role design decisions especially compared to a conventional building method. Because CitizenM is both a developer, project manager and end-user of the building, therefore there is a greater interest in delivering the project as well as possible. Due to the extensive experience in modular projects, CitizenM plays an important role in providing information and introducing a modular system to the local parties. The customer also has an active role in making important decisions and understands very well that these decisions cannot change later. That being said you can really tell that CitizenM acts as the real System Architect deciding upon the design rules related to the product architecture.

Furthermore, it is noteworthy that the local general contractor was not involved in the development process, as a result of which a modular product was assigned to him, whereby he had no control over the design. What is striking in view of he who is responsible for the entire execution of the building, and the modular supplier is a sub-supplier.

Mapleton crescent SW18

The Mapleton Crescent project was a special project, not only because it is one of the tallest residential modular buildings in Europe, but also because of its special aesthetic pleasing appearance. Within the Mapleton Crescent project, there is decided to use a Design and Build PDM after a two-stage tender. The building is designed by the architect according to a design task provided by the client. Originally it was a single-stage Design and Construct tender After the tenders turned out not to be financially feasible, except for the modular contractor. The client, who was familiar with modular construction methods from previous projects, nevertheless had doubts about the technical possibilities of the modular construction methods. Thanks to the Pre Service Contract Arrangement (PSCA), the modular contractor, together with its regular consultant partners, has been able to remove these doubts. The respondents logically experienced PSCA as an important key moment in the feasibility of the project. After the PSCA phase, there was decided to use a Design & Build contract, as preferred PDM for the whole portfolio of Pocket Living.

In the second stage, it was decided to use a Design & Built PDM as the preferred PDM of Pocket Living across the whole portfolio. That is mainly because of the external environment selection criteria. The local authorities of London including financial banks provided Pocket Living a £150 million financial fund to realize 1059 affordable homes in the private sector by march 2012: 'This was effectively a pre-condition of the Greater London Authority funding that Pocket benefitted from for the purposes of risk management. In a Design and Build contract, the Principle Contractor carries the majority of the project risk.' (Edwards, 2019).

Also, the customer no longer wanted to be responsible for the design or implementation, which makes sense as the modular system was developed by the supplier (Table 4).

Table 4. Overview of case study results (source: own illustration).

	The Fizz Spartaan	CitizenM Bowery	Mapleton Crescent SW18
Purpose building	Student apartments	Hotel	Residential
Budget	€17.186.000,-	$70.000.000,-	23.700.000,-
Number of modules	389	210	243
Construction time	12 months		20 months
Project Delivery Method	Turnkey	Design-Bid-Built	Design & Construct
System Architect	Contractors	Client	Contractor
Modular knowledge present during Designphase	Project developped entirly by contractors due through Turnkey agreement	Hotel room concept developed with modular supplier	After tender the design wasn't economically feasible, the modular contractor was the only feasible tender. After the tender a Pre-Service Contract Arrangement was drawn up to investigate the opportunities.
Retraining movement client	By turnkey contract all execution responsibilities to the contractors	Modular supplier involved during design phase and during realization phase as mandatory supplier	After tendering the Design-Bid-Build contract was transferred into a Design & Build contract
Early design freeze	Prototype is made to final check the design	Assesment on the quality of the first module of the product line	Assesment on the quality of the first module of the product line

Cross case analysis

It is important to note that all three cases have used different project delivery models: Turnkey for The Laan van Spartaan, Design-Bid-Built for Bowery, and Design & Build for Mapleton. As a result, it is not possible to reach a consensus directly from the collaboration forms used in this case studies. The results of the case studies can be summarized by drawing up a client's profile and comparing the client's profile with the chosen PDM, see Figure 2.

Retraining movement client

However, it can be stated that in every case the client wants his responsibility in the execution to be as minimal as possible. For the Laan van Spartaan and the Mapleton-case, this can be explained by the fact that the modular contractor determines the design rules and with that, they are the system architect. Because the customer won't bear the risk for a modular building method where he isn't the system architect. This somehow correspondents with the research of Blismas et al. (2005) that a client doesn't want to commit to a single one supplier as a risk-averse measure. In each case, the retreating movement of the customer is tackled differently:

- For example, in the Fizz Spartan case, the client has chosen to place the responsibility with the implementing parties by entering into a Turnkey agreement with their contractors. The client had a number of requirements and wishes that the building had to meet as a minimum, but what it should look like and how it should be realized was for the contractors' full responsibility. The client did not want to bear any responsibility for the product developed by the contractors.
- In the Bowery case, the modular supplier designed and developed along with the design team as a consultant during the design phase. An agreement was immediately reached with the customer about the price per module during this design phase. Subsequently, a local contractor was hired for the local conventional construction work whereby he was assigned to the modular supplier as a mandatory subcontractor/supplier. As a result, the General contractor was fully responsible for the production of the modules and the assembly of those modules into an entire building.
- In the Mapleton case, there is a withdrawal movement from the Pocket Living client due to a Design & Build PDM. Pocket Living had the building designed up to preliminary design in conventional building methods and was actively involved in this. Subsequently, with the arrival of a modular supplier Vision Modular, the contract form was adjusted to a Design & Build form in which only they had a direct contract with Pocket Living. From that moment on Vision modular was fully responsible for both the finalization of the design and the production of the modules plus their assembly.

Modular knowledge in design phase

It is remarkable that in all cases somehow the modular experience is present in the design phase. That identified need for modular knowledge at an early stage corresponds to the recommendations made in the study of Blismas et al. (2005, p. 160), who also suggested that: 'Early advice to the client and design teams would encourage design freeze by explaining the consequences to prefab modular solutions'. However, the presence of modular knowledge is tackled differently in every case. The differences can be explained by the ever-present need for the value for money that a client has:

- For example, the development of the CitizenM hotel room concept was done in collaboration with the modular supplier. In the Bowery case, the modular supplier was also involved as a consultant during the design phase. Later the modular building system was discounted and as a compulsory subcontractor, it was part of the competitive tender.
- The Mapleton case also required modular knowledge after other tenders were not economically feasible. Before the conventional assignment was changed to a modular assignment, there was a period in which the feasibility of modular systems was investigated in the Pre-Service Contract Arrangement of a Two-stage tender. The presence of a modular contractor right from the start of the project is not preferred because it is then more difficult to get a value for money.
- In the case of Laan van Spartaan, they worked directly with the modular supplier. The system architect of the modular solution is the contractors. The need for value for money has been solved by the chosen PDM, whereby a maximum price is immediately indicated by the customer in the Turnkey agreement. This way, contractors know immediately whether certain design solutions are possible or not. The customer does not want to pay anything that costs more.

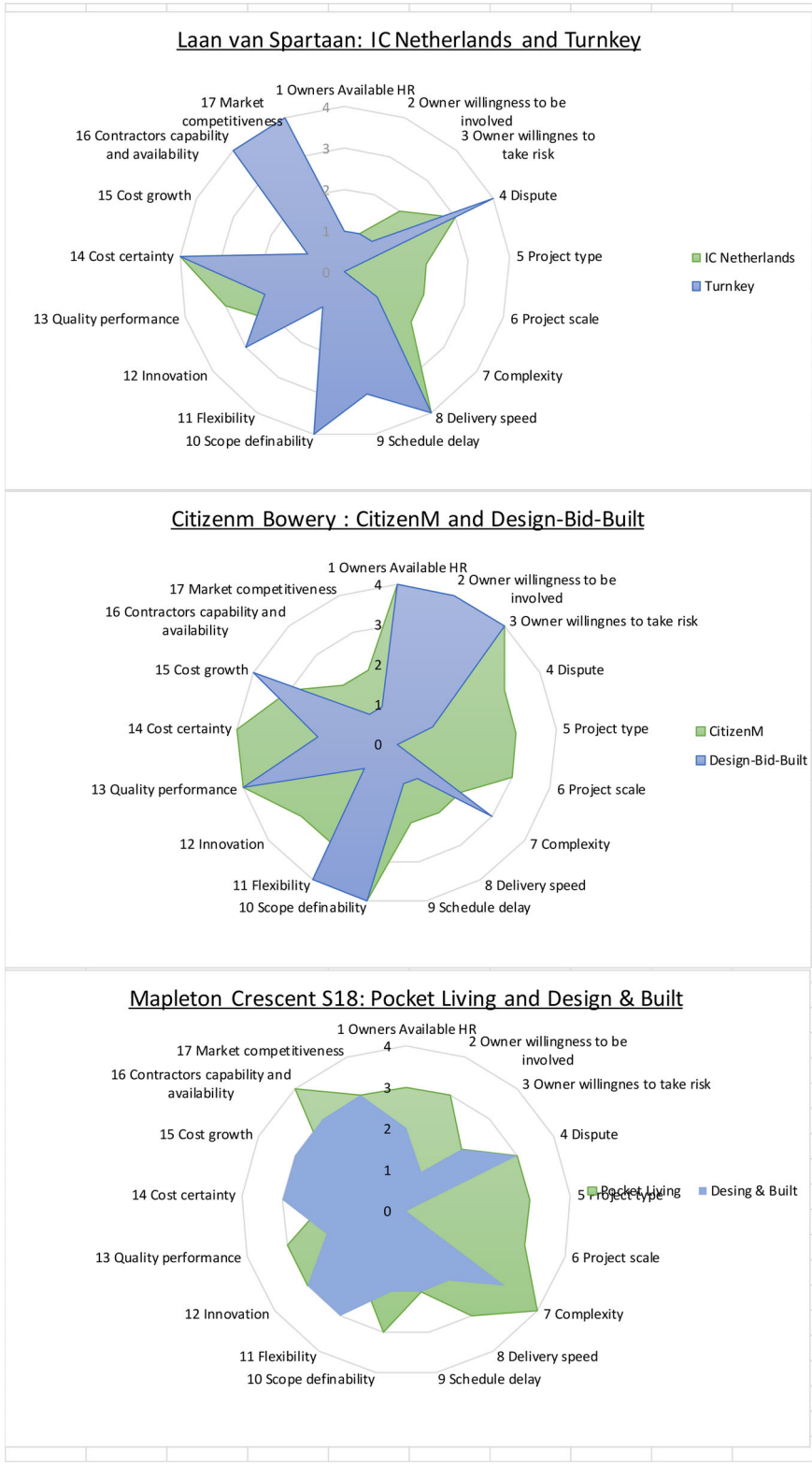

Figure 2. Spider charts comparing the results of the case study client's profile with chosen PDM Source: (source: own illustration).

The best solution for consulting the modular knowledge in the design process depends on the type of customer and the desired involvement. Is a building realized as a one-off development or as an actual concept that is realized several times? If a customer does not want to be very involved and wants to outsource the development of the design, the solution as used in the Laan van Spartaan can be used, whereby a fixed budget guarantees the value for money. However, if one wants to make more of a repeated development, one is more bathed in one.

Still uniqueness

Although clients work in concepts, like CitizenM has the hotel room-concept, and Pocketliving has the concept of Pocket

homes, the development of new buildings is always treated as a project. For example, for each project, CitizenM asks two modular suppliers who want to build it, despite the fact that they have a growth ambition for the coming years. The same applies to Pocket Living where there is a goal for a certain number of first-time buyer homes. If one wants to make full use of the possibilities of modularity, the development of a modular system would require more a product-based approach and the associated forms of cooperation.

Lack of serial tendering

For example, none of the cases uses a framework contract or serial tendering between a client and a modular supplier, whereby a declaration of intent is signed for several buildings. Up to now, contracts have always been a project-to-project approach. This is partly because customers always want value for money that includes a competitive tendering. Customers do not want to depend on one supplier for a longer period.

Discussion

The ever-growing urbanization demands a strong need for high-rise projects in the city. Smaller construction sites and stricter regulations in an urban environment require different construction methods. Modular construction can be a possible solution for this social need. This article can provide an answer for clients and companies who are considering using modular construction methods for a high-rise project. It offers a framework how collaboration can be organized to overcome the process-related barriers of modular high-rise projects.

Modular building is a widely researched topic in academic literature, an increasing number of studies have been presented in recent years. Worldwide there is a lot of research into specific characteristics, the advantages and structural implications that accompany the application of modular building methods with a special focus on a high-rise application. Research has been conducted mainly into the barriers that prevent the use of modular building methods. However, this article focuses on the required organization forms within modular high-rise projects. Organizational forms in modular high-rise projects have received little attention in academic literature to date.

The results of this study are consistent with the results of the literature. Blismas et al. (2005) and Wuni et al. (2020) shows that the barriers for the introduction of modular construction such as the need for the more intensive cooperation between more project partners, require more effective communication. Key decisions must be made at an earlier stage in order to achieve a more detailed design freeze. Different Project Delivery Models can all offer an answer to these barriers in their own way. The most suitable PDM depends on the specific characteristics of a client per project. This results in no specific PDM being a generic match for modular high-rise buildings. The results of the case study confirm this; in all three cases, three different PDMs were used. Therefore, it is not possible to reach a consensus directly from the collaboration forms used in this case studies.

Both theory and practice show that the far-reaching execution knowledge of modular systems is unmistakable during the design phase. How this modular knowledge is added in the design phase differs per case, but this fact works to the detriment of the traditional PDM Design-Bid-Built. In general, the traditional DBB model is not particularly well-suited to modular construction methods. When tendering out the project the design has advanced to the point where the team may be unwilling or unable to make changes to optimize for modular construction. In this case, the general contractor would never want to be responsible for the implementation and assembly of constructively self-supporting modules and this would always lead to discussion, as was in the CitizenM Bowery case. Because the general contractor remains responsible for the execution of a building. Otherwise, this also applies to the customer, as is shown in the case of the Laan van Spartaan case and Mapleton Crescent. Here the modular concept was developed by the implementing parties. In such a situation, the customer will never want to bear the risks for the design. The client will pass this through to the contractor or supplier since they have fully developed and tested the product. This correspondents with the research of Blismas et al. (2005) that a client doesn't want to commit to a single one supplier as a risk-averse measure.

The need for execution knowledge during the design phase requires PDMs in which there is a less rigid dividing line between the designing parties and the implementing parties. This calls for more integrated PDMs such as Early Contractor Involvement, Turnkey, or Design & Build. What is the best choice between them depends on a number of things. If for example a client has a strong need to be involved in the project and wants to develop a modular concept that can be applied more often an Early Contractor Involvement PDM could be the most suitable. Otherwise, as soon as the customer sees the building as an investment and is not the building owner or end-user, he wants to be less involved and obtains for a Turnkey PDM, as in the case of the Laan van Spartaan case. A Design & Build PDM is a variant that sits between the two situations: The client has a need for interference in the design that is made from the modular concept but ultimately does not want to be responsible for it.

A striking result is the absence of a long-term recorded or binding contractual form of collaboration, so called serial tendering, between different parties. This while modular building mainly revolves around continuous improvement of the modular building system and therefore benefits from a long-term partnership. This can be explained by the fact that the construction industry is characterized by a project-based character, in contrast to the product-based properties of a modular construction system.

Conclusion

Modular building is about developing building concepts that can be applied multiple times, whereby construction projects must be designed independently. Modules must be interchangeable through equivalent interfaces. This is the opposite of the current construction industry where a one-off project is realized by a unique composition of project partners. It can be said that modular construction is a change from project collaborations to product development.

It should be noted that, unlike the manufacturing industry in the construction sector, a unique factor always remains. As the CitizenM Bowery case shows, a 'hotel-room' concept has been developed, but due to the constantly changing local circumstances (local regulations, local land, earthquake zones), the modular concept must be adapted every time. Modular construction requires a completely different form of collaboration between partners. Modular building concepts benefit from long-term relationships between permanent partners in order to go through a

constant development curve. Where a concept is developed in collaboration with a permanent architect, modular supplier and additional design consultants who can meet the requirements.

It is debatable whether the current organisation forms or Project Delivery Models (PDMs), meet the needs for modular concepts. As the name suggests, the six most common PDMs of the construction industry are all focussed on a project-based approach. Concepts will benefit more from a Product Delivery Model on which fixed partnerships arise based on mutual dependence. Making a strong argument for new Product Delivery Models such as described in the theory of De Ridder (2011), who argues that the modular supplier not only deliver the product but also has a standard contract that belongs to the product, including terms and delivery conditions, just as a normal consumer transaction guarantees. Changing this approach requires a completely different construction industry. Until then, modular structures will be realized with the current PDMs and the best match would have to be sought. What that best match is, depends on many factors such as customer characteristics, project characteristics and the market environment that differ in every building. That's why there is no one best solution.

Modular construction requires in-depth knowledge of execution in which certain key decisions must be made early in the design in order to freeze the design. Due to this characteristic of modular construction, the PDM Design-Bid-Built in which the construction parties are not involved in the design is less suitable. Besides that, heavily administrative PDMs such as DBFMO and Partnerships cannot meet the fast decision needs associated with modular construction. This requires a client who can make decisions quickly. Because a DBFMO and a Partnership PDMs have a rigid organizational form in which decisions are made about different management disks, these PDMs are less suitable.

Making the more integrated PDM's such as Early Contractor Involvement, Design & Build, or Turnkey more suitable for modular construction. In these PDMs, the hard separation between the design phase and the implementation is blurred, so that the design and implementation have an overlap with each other. Modular implementation knowledge can be consulted from the start of the design phase, in the role of either a consultant or as an implementing party. Which of the three PDMs is ultimately the best match differs greatly in the customer profile. Does the client see modular construction methods as an option for a one-off project? Or does the client want to develop a real concept as a system architect through modularity? In other words, the client has the need to be a system architect or not.

The actual most suitable PDM is dependent on the client profile that can be determined by the 17 selection criteria. A client gives scores of 0 to 4 per selection criteria that meet his needs. The best match of the client profile with the characteristics of each PDM can be visualized by a spider chart.

Limitations

There are two design limitations in this study that must be acknowledged while interpreting the results of this study.

The first limitation concerns the stakeholders. Only direct stakeholders such as customer, designer and supervisor were involved in the research. For a more extensive stakeholder analysis this can be expanded with involving bodies such as municipalities, urban planning and certification bodies. In particular, they have a different perspective when it comes to standardization and certification in terms of approval of the modules per se and the entire building.

The second limitation lays in the fact that there are three cases in three different countries investigated. Culture differences between the different cases aren't taken into account when analysing the results. It could be that different outcomes are typical of a certain location/country, which means that information cannot simply be generalized. Whether this is actually the case is not known. A possible follow-up study can take this into account in the future by only looking for cases at the same culturally bound location.

Acknowledgments

The authors also wish to thank the interviewed (project)managers, and the anonymous reviewers.

Disclosure statement

No potential conflict of interest was reported by the authors.

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