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# Categorizing modularization strategies to achieve various objectives of building investments

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## ABSTRACT

Modularization has recently attracted considerable interest among academics and practitioners. In the construction industry, several modular solutions have been introduced and examined; however, hardly any study comprehensively classifies the different modularization strategies according to their possibility to achieve various objectives of building investments. This research aims to develop a framework for identifying and classifying modularization strategies in construction according to their suitability to achieve the specific outcomes intended for a building or its subsystem. Using the literature on product modularity, product platforms and production strategies as a basis, this study has developed a theoretical framework that proposes connections between the main objectives of a building investment and the dimensions of modularization strategies. The framework is elaborated by testing the propositions, based on an empirical analysis of nine real-life case studies. The findings reveal that modularization can be a suitable approach to develop an innovative design solution; improve a project's quality, cost and schedule performance; and enable flexibility in building use and maintenance. However, suggestions for achieving these objectives vary from project organization-driven to collaborative, integrated or supplier-driven modularization strategies. Developers, owners, contractors and module suppliers can use the framework when positioning and developing their roles in the construction supply chain.

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product architecture;  
product platform; production  
system; building investment

## 1. Introduction

Because the construction industry produces complex and unique products, involving many stakeholders and processes, modularization has been perceived as an appealing approach to improve efficiency, flow and quality (Gibb 1999, Lawson *et al.* 2012). Modularization is a way to decrease the complexity of systems by building them from smaller subsystems (or modules) that can be designed independently yet function together as a whole (Baldwin and Clark 1997). In construction, modularization plays a role in modular-sized design options, prefabrication of subsystems, standardization and industrialization of processes, enhancing customer value and making processes more efficient in terms of resources and time (Burke and Miller 1998, Gibb and Isack 2003, Ågren and Wing 2014, Jonsson and Rudberg 2014, O'Connor *et al.* 2014).

The research on modularization in construction has suffered from varying definitions of the terms *module* and *modularization*. Boundaries between prefabrication, preassembly, modularization and offsite fabrication are often seen as blurred (Gosling *et al.* 2016). Additionally,

research on production systems, such as preassembly strategies (Gibb and Isack 2003) and industrialized buildings (Jonsson and Rudberg 2014), has left modules with a rather narrow role as highly standardized preassembled volumetric units, which form the actual building itself. However, as modularization is based on a modular product architecture – the scheme by which the product's function is allocated to physical components (Ulrich 1995) – modularization in construction can cover a wide set of strategies to utilize subcomponents, components and non-volumetric and volumetric elements that enable the design and assembly of mass-customized buildings. Modularization is a strong concept that explains not only the architecture of products but also the organizations and processes for designing and producing them (Baldwin and Clark 1997, Fine 1998, Kusiak 2002, Salvador *et al.* 2002, Arnheiter and Harren 2005). Therefore, modularization in construction cannot be separated from the new division of tasks and roles among different stakeholders in the supply chain.

Modularization affects the potential to utilize prefabrication, preassembly and other production methods

and thus the final outcomes of a building investment. Therefore, before considering the adoption of modularization in the building investment, the crucial question is as follows: What is the problem that modularization is aiming to solve? The earlier research focus on modularization in construction may not always have been completely sharp in terms of providing new knowledge about specific outcomes, such as quality improvement through modular construction (Johnsson and Meiling 2009), design configuration utilizing industrialized platforms (Wikberg *et al.* 2014) and implications for maintenance costs (Pan *et al.* 2007), among others. These studies provide practitioners with useful knowledge about how to utilize modularization and similar concepts in specific settings and specific parts of the construction supply chain, but they do not extensively describe the variety of modularization strategies. Gosling *et al.*'s (2016) research on categorizing modules in building projects is a welcome addition to the discourse. Combining the idea of different modular product architectures and organizing forms with objectives of modularization creates a good basis for categorizing appropriate modularization strategies according to their intended outcomes. Modularization strategies that position themselves between pure standardization and pure customization (Schoenwitz *et al.* 2012) can provide solutions to different sets of managerial problems, ranging from project outcomes, such as time, quality and cost, to broader performance aspects of buildings, including innovativeness and flexibility in use (Jonsson and Rudberg 2014, Gosling *et al.* 2016). Considering a modular building only as an extreme case of industrialization leads to the impression of a predetermined lack of innovativeness and flexibility (Jonsson and Rudberg 2014), whereas the concept originally promises to fulfil a variety of customer needs through loose coupling of components (Sanchez and Mahoney 1996). The degree of modularity depends on the components used, their interfaces, the character of the coupling and the opportunity for replacement (Mikkola 2006).

There remains the need for a convenient categorization of modularization strategies in construction according to the adopted product architecture and organizing form, as well as different modularization strategies' suitability for achieving varying sets of managerial objectives of building investments. Thus, the purpose of this research is to develop a framework for identifying and classifying modularization strategies in construction according to their suitability for attaining the specific objectives set for a building investment. In doing so, we argue that modularization strategies can be adopted, not only to solve project-phase problems but also to gain advantages in the post-construction phase, and that the appropriate strategy varies according to the set objectives. In developing

the framework, the following research questions are addressed:

- What are the most relevant dimensions for classifying modularization strategies in construction?
- In what ways do different modularization strategies achieve various objectives of the building investments?

The research is divided into two phases. The first phase focuses on developing a theoretical framework that integrates earlier research on modular product architecture, product platforms, production systems and objectives of building investments. A product life cycle approach, adopted from the theory of modularity (Baldwin and Clark 1997), is used to differentiate the objectives of the investments spanning the entire life cycle of a building. The theoretical framework proposes connections between the main objectives of the building investment and the dimensions of the modularization strategies. In the second phase, the theoretical framework is further elaborated by testing the propositions, based on an empirical analysis of nine real-life case studies of modularization strategies. The final framework contributes to existing knowledge on modularization in construction in two ways. First, the framework expands the understanding about the outcomes of different modularization strategies by highlighting their potential benefits, not only in project phases but also during the post-construction phase, through innovative design solutions and flexibility in use and maintenance. Second, the framework elaborates on the knowledge about modularization by specifying the connections between the main objectives of the building investments and suitable dimensions of the modularization strategies.

## 2. Modularization strategies in building investments

The following sections provide a review of the literature on modular product architecture, product platforms, production systems and problems that modularization can solve in building investments. The literature review forms the basis for defining central concepts and creating a framework that can be used to categorize modularization strategies according to their ability to achieve specific objectives of the building investments.

### 2.1. Modular product architecture and product platforms

The adoption of a modular product architecture lies in the core of any effort to utilize modularization in the production system. A modular product architecture differs from integral architecture as the former includes a one-to-one

mapping from the functional elements to the physical components of the product and specifies de-coupled interfaces between components (Ulrich 1995). Modularity becomes a product's attribute when modularization, the activity to structure a product in modules, occurs (Miller and Elgård 1998). Loose coupling between components (modules) enables product variants to be created by mixing and matching components according to the functions that each customer needs (Bask *et al.* 2011). Salvador (2007, p. 232) also emphasizes that functions are hierarchical and that a single component should implement a specific "package of functions" rather than a specific single function. This kind of "function sharing" (Voordijk *et al.* 2006, p. 602) at the component level is reasonable if subfunctions are typically required in specific sets. In construction, a good example is an exterior wall that typically should include several functions, such as space creation, waterproofing, insulation and load bearing.

The component interfaces of modular systems can be organized in three ways (Ulrich 1995), as follows (Figure 1):

- In *slot architecture*, each interface between components is of a different type from the others, meaning that a product's various components cannot be interchanged.
- In *bus architecture*, other physical components connect to a common bus component via the same type of interface.
- In *sectional architecture*, all the interfaces are identical, with no single common component to which other components attach.

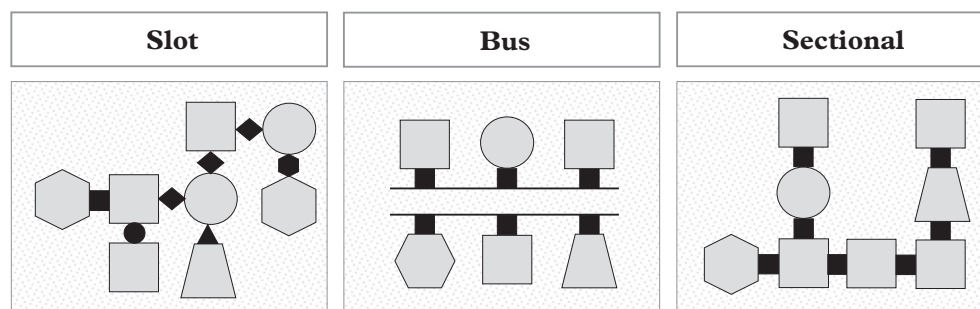
Empirical analyses in construction have proven that all types of architectures exist and that one modular system can include different types of modularity at different levels (Voordijk *et al.* 2006). Cut-to-fit modularity, where the interface of the module (e.g. wall element) remains the same but the dimensions can change, is a common type of slot architecture in construction (Jensen *et al.* 2012). Bus architecture allows variations in the components' locations (Chun-Che Huang and Kusiak 1998); for example, it can be used when bathroom pods are placed on a common

foundation. Sectional architecture with identical interfaces is utilized when a building is assembled from volumetric and prefabricated modules.

From the product supplier's perspective, modular product architecture can be part of the creation of a product platform, defined as the collection of assets shared by a set of products (Robertson and Ulrich 1998). Continuous development and reuse of shared assets, including components, processes, knowledge and people and relationships, provide companies with a greater ability to tailor products to different market segments and reduce the development cost and time. Although product platforms are potentially useful in sharing and accumulating knowledge in construction (Styhre and Gluch 2010), decreasing costs and improving quality (Thuesen and Hvam 2011), their application is still relatively low. Jansson *et al.* (2014) argue that the dominant engineer-to-order (ETO) production strategy hinders the implementation of fully parameterized platforms. Similarly, if the design specification process is based mainly on client requirements, codes and standards, there is no space for using generic product structures and standard parts and modules (Jensen *et al.* 2012). Therefore, the selected production strategy for a building investment can be argued as a crucial factor that also determines the potential to utilize modular product architecture and suppliers' product platform assets and their benefits for the building investment.

## 2.2. Strategies to adopt modular product architecture

A production strategy comprises decisions about the processing equipment, factory layout, automation level, organization of the production and planning methods (Skinner 1985). Similarly, a modularization strategy should consist of these dimensions, specifying the use of modular product architecture. Decisions about the production strategy should be made in parallel with those about modular product architecture (Guðlaugsson *et al.* 2016) (i.e. a building's decomposition into components and their functions, as well as types of interfaces between



**Figure 1.** Slot, bus and sectional architectures of component interfaces.



components) since issues related to the production strategy, such as factory layout or automation level, may even be drivers for using a modular product architecture, not vice versa. To be successful, a modularization strategy must be incorporated at project inception (Burke and Miller 1998), considering the competitive priorities (Jonsson and Rudberg 2014) set for the building investment. Challenges in implementing modularity in building projects are typically connected with management aspects, involving the behaviour of stakeholders and the project team (Pasquire and Gibb 2002). The use of function-related standardized components and loose interfaces between components can represent many changes in projects, placing new demands and complexity on project organization, engineering, procurement, planning, monitoring, coordination, communication and transport (Tatum *et al.* 1987).

Several attempts have been made to categorize modular and related production systems in construction (Gibb and Isack 2003, Jonsson and Rudberg 2014, 2015, Gosling *et al.* 2016). Generally, those classifications divide production systems into the following four categories, according to the degree of product standardization and offsite production:

- (1) *Modular buildings*: These preassembled volumetric units by themselves or when connected to each other form the actual building (e.g. houses, prison blocks, motels), signifying the highest degree of offsite production and standardization.
- (2) *Volumetric preassembly*: Volumes of specific parts in the building are produced offsite and assembled onsite within an independent structural frame (e.g. sanitary systems, toilet pods, shower rooms).
- (3) *Non-volumetric preassembly*: These preassembled units do not create usable space (e.g. heat generators, structural frames, wall panels).
- (4) *Component manufacture and subassembly*: This is the traditional approach in construction. Raw materials and components, such as bricks and mortar, are used for building onsite, indicating high degree of customization and the lowest degree of offsite production.

The set of the first three categories provides a good basis for investigating modularization strategies since the distinction among them is based on the hierarchical packaging of functions embedded in a single component. In modular buildings, the packaging of functions (Salvador 2007) is the most comprehensive, whereas non-volumetric preassembly more strictly follows the idea of a one-to-one match between functions and components. These four categories have been mainly distinguished to clarify production systems for preassembly (Gibb and Isack 2003)

and industrialized building (Jonsson and Rudberg 2014). Therefore, for the purpose of this research, the classification provides a fruitful but still rather narrow approach to modularization strategies as they focus mostly on process issues, such as implications for project operations (Gosling *et al.* 2016), while neglecting the organization of production and the roles of different stakeholders in the building investment. Research on product platforms (Jansson *et al.* 2014) and product customization (Hvam *et al.* 2008, Jensen *et al.* 2012) indicates that modularization requires customers to move from ETO production strategies to configure-to-order (CTO) or assembly-to-order (ATO) strategies, in which the customer order specification decoupling point changes. Thus, the respective roles of the customer and the supplier also differ from those they perform in traditional construction. Recent research has not considered this organizational dimension in modularization strategies.

The other gap in the existing categorizations of modularization strategies involves the differences in how the strategies could achieve the specific objectives of building investments. Most of the reported benefits of modularization focus on project-level issues, such as improved labour productivity and resource efficiency, reduced costs and time, fewer onsite labour activities, less dependencies between activities, improved quality control and higher quality finishes (Gibb 1999, Haas *et al.* 2000, Pasquire and Gibb 2002, Pan *et al.* 2008, Johnsson and Meiling 2009, Isaac *et al.* 2016). Jonsson and Rudberg (2014) argue that a higher degree of offsite production improves project-related outcomes, such as delivery time, cost and quality, but limits the building's flexibility and innovativeness. However, the original idea of modular product architecture is that it also supports product change during the use phase by allowing each functional element to be modified independently by altering only the corresponding component (Ulrich 1995, Arnheiter and Harren 2005). Erixon *et al.* (1996) contend that maintenance, upgrading and recycling are easier if separated modules are used for subfunctions. Additionally, Gosling *et al.* (2016) give examples in which modularization improves flexibility in the post-construction phase through an adaptable layout and loose interfaces that facilitate the maintenance of building systems. The idea of a product platform also facilitates flexibility in the post-construction phase because platform owners maintain and develop assets and capabilities related to their products and interfaces for a long time after the project phase of the building investment. Projects end, but platform suppliers exist to deliver after-investment services. Ulrich (1995) also emphasizes that a modular product architecture enables an infinite variety if components are fabricated to order. This means that it is possible to achieve not only flexibility but also innovativeness by utilizing a modularization strategy.

### 2.3. Central concepts and theoretical framework

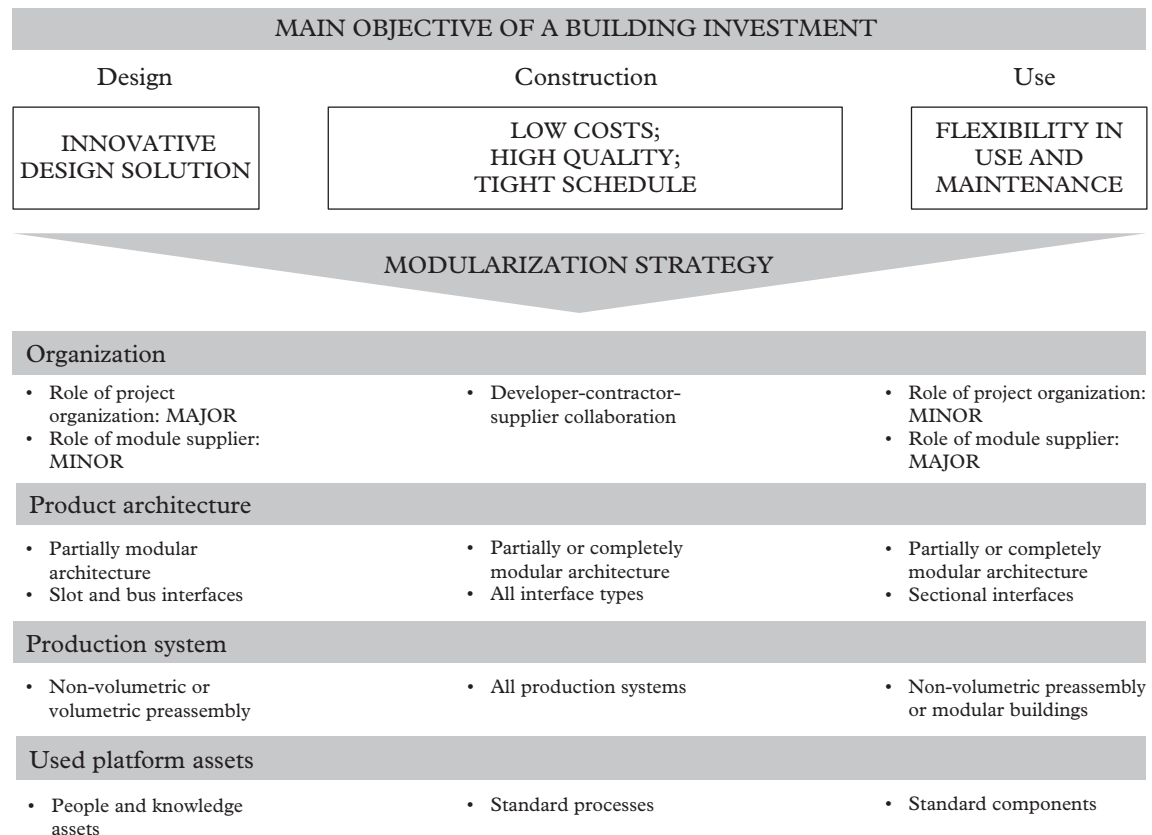
Based on earlier research on modular product architecture, product platforms, production systems and their manifestations in construction, the following concepts and their definitions are used in this study:

- A *module* is a self-contained component with a standardized interface with another part of a building. It includes several functions, divided into several components in traditional construction (Ulrich 1995, Voordijk *et al.* 2006, Salvador 2007, Bask *et al.* 2011).
- *Modularization* is the activity in which a building is structured into modules (modular product architecture), at least in its essential parts (Miller and Elgård 1998, Voordijk *et al.* 2006).
- *Modularization strategy* comprises decisions about modular product architecture (modules and their interfaces), the production system and the organization of the design and production to utilize platform assets in a specific building investment (Ulrich 1995, Robertson and Ulrich 1998, Gibb and Isack 2003, Jansson *et al.* 2014, Jonsson and Rudberg 2014, Gosling *et al.* 2016).

In combining the concept of modularization strategy with earlier research on the outcomes of different modular

product architecture and production systems, a theoretical framework is developed to categorize modularization strategies according to the objectives of building investments (Figure 2). Such objectives (Jonsson and Rudberg 2014) can be identified in a building's life cycle (Gosling *et al.* 2016), according to the phase where they exert the most effects. Innovative design solutions are enabled by activities in the design phase. Low costs, high quality and a tight schedule require modifications in the construction phase and flexibility in use and maintenance demands that the use or the post-construction phase be taken into account.

The framework states that modularization strategies vary in terms of their organization, product architecture, production system and used platform assets according to the objectives of an investment. In contrast to previous research that emphasizes that modularization always aims to gain benefits in the construction phase, related to improved cost efficiency, quality or schedule (Gibb 1999, Haas *et al.* 2000, Pasquire and Gibb 2002, Pan *et al.* 2008, Johnsson and Meiling 2009, Isaac *et al.* 2016), our framework highlights that in addition to those objectives, modularization can aim at innovative design solutions if project stakeholders' knowledge assets (Robertson and Ulrich 1998) related to modularization are used when designing repetitive spaces or structures, and they are connected to a fabricate-to-order strategy (Ulrich 1995). At the other



**Figure 2.** Theoretical framework for classifying modularization strategies according to the main objectives of building investments.

extreme, flexibility in the use and maintenance of a building is possible if module suppliers are given higher autonomy to utilize their standard interfaces and components as platform assets that enable a scale economy (Thuesen and Hvam 2011), not only during the project but also in post-construction services. Modularization strategies that aim at improved performance during construction can be located between the extremes as they often require the use of standard offsite production processes of module suppliers but not necessarily fully standardized components or interfaces. Therefore, the project organization's role in design and delivery can be greater than when aiming at flexibility in use and maintenance.

Based on the theoretical framework, three fundamental modularization strategies can be differentiated. An *innovative design solution* requires the project organization, involving the project owner, designers and contractors, to play a remarkable role in defining which features are included in the innovative design solution. The project organization focuses on designing a crucial and repetitive space or element in a building as a separated module, such as a bathroom in a hotel or a patient room in a hospital. The component supplier can be hired to prefabricate and deliver the module, but it performs a minor role in designing the solution because the supplier's inherent incentive is to use more scalable and mature design solutions (Hofman *et al.* 2009). Due to the project organization's scarce resources, the modules often comprise only a part of the building and are connected to an integral building structure via project-specific slot or bus interfaces (Ulrich 1995). Existing knowledge and relationships, especially among designers and contractors, can be used as scalable platform assets in innovation work. This point leads to the first proposition:

P1: If modularization aims at innovative design solutions in repetitive structures and spaces, a *project organization-driven strategy* to utilize the modularization knowledge of project stakeholders, such as designers and contractors, should be adopted.

*Improved performance in the construction phase* through modularization, whether that performance is related to cost, quality or time, requires adopting a prefabrication- and preassembly dominated modularization strategy, using an industrial production environment (Jonsson and Rudberg 2014). Task division between the project organization and component suppliers may vary according to the context and available resources. The main platform assets used for an improved outcome are not necessarily standard components but are standardized processes to manufacture, preassemble, deliver and assemble components onsite. The following proposition is suggested:

P2: If modularization aims at improving the cost, quality and/or schedule performance of the project phase

without specific targets for innovativeness or the post-construction phase, a *prefabrication- and preassembly-driven strategy* to utilize standard processes should be adopted.

*Flexibility in use and maintenance* requires that single components can be removed and replaced. Volumetric preassembly is typically not possible as volumetric modules, such as bathrooms, often have complex and rather fixed interfaces to other structures. In order to enable replaceability during building's life cycle, design rules about components and their interfaces should remain rather stable. Design rules can be industry-wide standards or as Hofman *et al.* (2009) argue, they have to be managed by the module supplier in order to enable component level replacements inside the modular system. Thus, we argue that for flexibility in use and maintenance, there is need for a supplier that owns the used modular product system and can provide supplemental components and services during the use phase of the building. As suppliers are unwilling to work to the new design rules (Hofman *et al.* 2009), the supplier should already perform a remarkable role in the design phase of the project because flexibility requires the supplier to utilize its standardized components and interfaces as platform assets (Robertson and Ulrich 1998). Industrialized suppliers can have resources to provide more complete modular buildings (Jonsson and Rudberg 2014) than project organizations, such as wholly modular buildings in which only the earthworks and foundations have to be customized according to particular circumstances. A complete modular architecture also enables the interfaces to be standardized across different functional components, using a sectional interface architecture (Ulrich 1995). Thus, the third proposition suggests:

P3: If modularization aims at flexibility in the use and maintenance of a building, a *module supplier-driven strategy* to utilize a supplier's standard components and interfaces should be adopted.

In summary, the theoretical framework integrates the literature on modular product architecture (Ulrich 1995, Voordijk *et al.* 2006, Salvador 2007, Jensen *et al.* 2012), product platforms (Robertson and Ulrich 1998, Styhre and Gluch 2010, Thuesen and Hvam 2011, Jansson *et al.* 2014) and modularization-related production strategies in construction (Gibb and Isack 2003, Jonsson and Rudberg 2014, Gosling *et al.* 2016). The framework's main contribution is its expansion of the current understanding about appropriate modularization strategies by matching them with the building investment problems that modularization can solve. The range of problems can vary from innovative design solutions to the traditional focus on project performance and flexibility in the building's use phase.

Notably, preassembly and prefabrication are typically also utilized in strategies that aim at innovative design

solutions or flexibility in use. However, the presented division of the strategies emphasizes the choice of construction processes as typically secondary in the first (P1) and the third (P3) strategies, whereas in the second strategy (P2), it is an essential and primary feature to achieve the intended project-phase outcomes. Additionally, a modularization strategy in a single building investment can have a variety of objectives; likewise, the objectives may vary among subsystems or spaces in the same building. This means that several production strategies should be adopted in a single project, making project management more complex and highlighting the importance of accurately defining the boundaries and interfaces between building subsystems that follow different product architectures and production strategies. Similarly, although we refer in the framework to the objectives of the whole building investment, the framework can be also utilized when considering only a single sub-system or one part of the whole building. When aiming at an innovative design solution, the framework even claims that modularization strategy can and should be adopted in a limited and carefully selected part of the whole building investment and the rest of the building should be designed and produced through conventional methods.

The framework is theoretical; therefore, in the following section, we test it by adopting it in nine case studies of different modularization strategies.

### 3. Research method

A case study was adopted to test the three propositions that were developed based on a guiding theory. A case study is useful for both generating and testing hypotheses, and hypothesis testing relates directly to the question of generalizability; in turn, it is linked to the question of case selection (Flyvbjerg 2006). The generalizability of case studies can be increased by strategically selecting cases and using atypical or extreme cases that often reveal more information because they activate more actors and more basic mechanisms in the studied situation (Flyvbjerg 2006).

For the purpose of this research, theoretical replication in the data collected from multiple case studies was sought during the analysis, where the cases were intended to cover different theoretical conditions (Yin 2013). These different conditions used in this research were defined, based on the theoretical framework and its distinctions among the various objectives of modularization, the types of organizing modularization strategies and the types of product modularity. The strategic selection of cases was also followed by the choice of extreme cases (i.e. that either aimed at an extremely innovative design solution or extremely high flexibility in a building's use and maintenance). Moreover, other types of cases in which the main

objective was related to the construction-phase performance or which had mixed objectives were chosen to fill all the conceptual categories (Eisenhardt 1989). This multiple-case study design enabled dissimilar manifestations of modularization strategies among cases to be produced but for predictable reasons (theoretical replication). A similar research design was previously adopted (e.g. Jonsson and Rudberg 2014); however, we aimed to recruit more than three cases as our framework also included several theoretical conditions.

In summary, available case studies were first reviewed. In this initial review, we used available public reports, documents and marketing materials of the cases and in some cases also preliminary interviews to derive the main intended objective of each system. Finally, nine cases from three countries (Brazil, the United States and Finland) were selected, based on three reasons. First, the cases covered all the different objectives that modularization was intended to achieve according to our theoretical framework. Second, public data and documents, such as case descriptions and newspaper articles, were easily available for most of the cases, facilitating access to secondary data when drawing case descriptions. Third, the chosen cases also offered the possibility to collect primary data in terms of onsite visits, along with unstructured and semi-structured interviews with representatives from the building owners, contractors, suppliers and designers participating and managing the modularization efforts.

Table 1 presents the case descriptions, each modularization's main objective and the collected data. In the data collection, triangulation was utilized as much as possible to improve the findings' validity and to develop converging lines of inquiry (Yin 2013). Available case reports and documents were first gathered from websites and through our contacts. Where possible key actors of the case companies were interviewed to map the characteristics of the cases. In order to allow informants freely express their views in their own terms, the semi-structured interviews covering the following themes were used without a rigorous set of questions: (1) objectives of the building investment and their priority; (2) characteristics of the used modules and components; (3) project stakeholders and their roles; (4) design, prefabrication, assembly and logistics processes; (5) verified outcomes if available; and (6) identified challenges. The interviews were recorded whenever possible and transcribed. At least two authors were present in each interview, increasing the findings' validity. The interview notes were also utilized in the analysis. In several cases, visits to the project sites or the module factories were organized, providing the opportunity to make observations, take photos of the processes and the modules and ask detailed questions about the products and the processes. To increase the construct validity (Yin 2013), we



**Table 1.** Description of cases and multiple sources of evidence (triangulation).

Case	Modularized system	Main objective	Multiple sources of evidence
(A) Prefabricated façade producer in Brazil	Prefabricated façade system	Quality	Two interviews with the producer–owner and the technical manager Visit to the production factory in Brazil Direct observation of the construction process onsite Product feature documents
(B) Prefabricated concrete wall system in Brazil	Prefabricated concrete wall system	Cost-efficiency	Three interviews with the technology, planning and production managers Visits to three production factories and five worksites in Brazil, which have a common owner Direct observation of the construction process onsite Analysis of design documents, budgets and schedules
(C) Prefabricated concrete element system in Finland	Concrete element system for residential buildings	Cost-efficiency	One interview with the development manager of the largest element provider Historical document on concrete element construction in Finland, produced by the Concrete Industry Association Guideline documents regarding the elements and their structures (element types, modular sizing, interface details)
(D) Bathroom producer in Brazil	Preassembled bathrooms	Quality	Two interviews with the operational manager and one production engineer Visits to two production factories and three worksites in Brazil Analysis of design documents, budgets and schedules
(E) Hotel project in California	Preassembled bathrooms	Quality	Interview with the project's general contractor Worksite visit Inspection of the model bathroom module
(F) Hospital project in Florida	Preassembled patient room wall components	Innovativeness	Two documents describing the project, written by the hospital designers Seven media articles on the project Two workshops with industry experts and consultants
(G) Hospital operating room producer in Finland	Turnkey operating room from prefabricated components	Quality	Four interviews with the representatives of component producers and one with a customer Visit to the production factory Product feature documents and assembly schedules Video of production process
(H) Hospital project in Missouri	Modular hospital building	Schedule	Two workshops with industry experts and consultants Interview with the module producer Visit to the module production factory Project background and progress documents produced by the building designers Floor plans Workshop with industry experts and consultants
(I) Modular building system producer in Finland	Transferable modular health care facility	Flexibility in use	Four interviews with the producer's representatives and five user interviews Visit to the module production factory and the healthcare facility site Product feature documents Video of production process Two workshops with industry experts and consultants

also organized two workshops (one each in California and Finland) with researchers, industry experts and consultants to evaluate the potentials of the four selected extreme cases and to triangulate the findings from archival records and the interviews. The workshops focused on identifying the cases' application areas, potential benefits and challenges.

In analysing the case studies, we followed a strategy that relied on theoretical propositions (Yin 2013). This meant that the three propositions developed in the theoretical part of the study shaped the data collection plan and therefore the priorities in the data analysis. In practice, we categorized the characteristics of our case studies, using the concepts of the theoretical framework – objectives, organization, product architecture, production system and used platform assets. As objectives,

product architecture and production systems were rather easily derived based on the documents, interviews and observations, organization and used platform assets were derived based on authors' interpretations on informants' views and opinions about the roles of different stakeholders in the investments, the task division between stakeholders, and ways how stakeholders cooperated during the project. The purpose of each case study was to analyse how the product architecture, organization and use of platform assets in the case were connected to the intended outcome of modularization. Extensive case descriptions were first written and utilized as discussion platforms among the authors. After the categorization of case characteristics according to the theoretical framework's concepts, a pattern-matching logic was used to compare the empirically based

patterns among the concepts in the cases with a predicted pattern of the theoretical framework. Finally, the cases' challenges were analysed to further evaluate the applicability and potentials of different modularization strategies.

## 4. Results

### 4.1. Characteristics of the modularization strategies in the cases

This section addresses the modularization strategies adopted in the nine cases, starting with within-case reports and followed by an analysis to test whether or not the cases replicate the research propositions.

#### 4.1.1. Prefabricated façade system in Brazil

The panellized light steel frame is a façade system applied as a high-quality and rapid-to-assemble alternative to the traditional processes of brick masonry with external finishes or concrete panels. The system's components are steel profiles, cement or glass fibreboards, water barriers and finishes. This specialized producer develops solutions in collaboration with each customer's project architect for different project types, such as hotels, commercial buildings and shopping centres. The non-volumetric panels may also include windows, glass and external painting. The producer manufactures and preassembles components in a permanent factory, transports panels and assembles them onsite, utilizing cumulated knowledge and standard processes. Before manufacturing starts, a prototype panel is produced, transported and assembled onsite, for testing and evaluation by the customer or the general contractor. The panels are fixed on the concrete structure with bolts, making it possible to disassemble some parts during maintenance or future retrofits.

#### 4.1.2. Prefabricated concrete wall system in Brazil

The developer created a preassembled concrete wall system in an attempt to reduce the construction costs and the schedule of its residential building projects. Seeking to provide a high level of repetition, the developer defined a product family by standardizing the apartment size and offering options with two or three bedrooms. The manufacturing process was integrated in the developer's business, and the company developed common product platforms with variations in the standard components. Over the last five years, the company produced more than 6,000 residential units. The non-volumetric components included precast concrete walls, slabs and stairs, containing inserted electrical installations. The components were manufactured in three temporary factories, transported

to the worksites and assembled by cranes or hoists, using standardized (sectional) interfaces between components.

#### 4.1.3. Prefabricated concrete element system in Finland

During the urbanization boom in the 1960s and the 1970s, the concrete element companies in Finland decided to standardize their products to increase productivity, cut delivery times and decrease the dependence on single companies and their designers. In practice, the industry-developed standards for prefabricated concrete elements, including non-volumetric end and partition walls, sandwich exterior walls and hollow core slab floors. The standard sizing of elements and standard sectional interface details involving the elements were the core knowledge assets of the system, enabling developers and construction companies to purchase the elements for one project from different producers. As a result, the concrete element industry assumed increased responsibility for the design, production, assembly and casting of joints, using standardized processes.

#### 4.1.4. Bathroom producer in Brazil

The specialized prefabricated bathroom producer offers standardized solutions to customers, with a view to improving product quality and reducing onsite work and materials. The volumetric preassembled bathrooms are used in projects that have repetitive space solutions, such as hotels, hospitals and commercial buildings. During the design phase, the technical team collaborates with the customer's architects in finding the most appropriate solutions in terms of bathroom modules and their bus interfaces with the building structure. The producer utilizes a standardized construction process, offering customers a variety of sizes, shapes and finishes to comply with the specific requirements of each building. The non-structural bathrooms are fully manufactured and assembled offsite in a permanent factory, including mechanical, electrical and plumbing (MEP) installations, ceramics, painting, countertops and water taps.

#### 4.1.5. Preassembled bathrooms in a hotel project in California

The general contractor decided to utilize prefabricated bathrooms in a high-rise hotel building to ensure high quality and speed up the construction process. In total, 890 bathrooms were fabricated and assembled on 46 floors. A specific project team, including several experts, was appointed to design the bus interface between the innovative bathrooms and the building. Seismic factors were considered in the connections. A model room was built first to define the quality requirements for the module producer. In the assembly phase, cranes first lifted the

modules to the floors. Then, each module was moved to the right location and installed on concrete slabs. Both the quality and the efficiency of the assembly work improved in the course of the project. During the first few days, the assembly team was able to install 4–6 bathrooms per day, and some rework was needed in the first floors. Later, the efficiency increased to 10 modules per day on average, with 12 modules per day as the maximum.

#### **4.1.6. Preassembled patient room wall components in a hospital project in Florida**

The construction manager and the design group collaborated extensively to develop preassembled construction methods to save costs and reduce the time of building the hospital. The team first designed and virtually constructed the standardized patient rooms and overhead MEP racks with an innovative layout and access to daylight and then fabricated and assembled them in an off-site warehouse. The BIM was first used to design a patient room as an entire portable volume. Instead of producing a fully volumetric room module, a more cost- and space-efficient solution was found – a non-volumetric room wall component that integrated the volumetric toilet room. The module included the patient bed and mechanical, electrical, plumbing and medical gas systems. The components were produced and preassembled in an empty furniture warehouse less than three miles from the hospital. Standard bus interfaces between each component and the building structure were used in the onsite assembly.

#### **4.1.7. Turnkey hospital operating room in Finland**

Three operating room technology companies launched a joint venture, offering turnkey operating rooms for hospitals. The offering is a package of the design service and the delivery of hermetic, clean room ventilation systems, along with an easy-to-use control system to monitor and manage operating room conditions. The advantages over the traditional decentralized design, purchase and construction of operating room components include a high-quality end product with better user experience, higher quality of assembly work and the possibilities to modify the room and equipment during the use phase. Sectional interfaces are used between clean room elements, as well as slot interfaces between equipment pieces and between the room and its environment. The system only requires a stable base floor, enough vertical space and connections of mechanical, electrical and plumbing systems to the hospital's systems. The room is assembled onsite, using a steel structure and preassembled wall components, a ventilation system and control system components. The components can be replaced as the technology evolves.

#### **4.1.8. Hospital project in Missouri**

The fully equipped interim hospital was constructed within a year to replace an earlier building that was destroyed by an F5 tornado. A completely modular building was selected by the developer and the designers. Both the hospital design and the production, delivery and assembly of the standard-sized fully equipped room modules were planned in advance in collaboration with the module producer. The hospital consisted of 224 structural steel and concrete modules manufactured in a Southern California company with a specialized production line for building modules. The modules were shipped to the site on massive semi-trailers and fixed to one another and to steel columns through standard interfaces. Only individual exteriors and specific requirements, such as medical gas, were installed onsite. The project's reported advantages included rapid delivery time and access to skilled workers through prefabrication.

#### **4.1.9. Modular building system producer in Finland**

The Finnish company fabricates transferable schools and day care centres, using preassembled volumetric units, which when connected to each other, form the actual building. Most of the buildings replace older ones whose use is prohibited because of indoor air and moisture problems. Fully equipped building slice modules are fabricated in the company's two factories and transferred to the customer's site. The modules include everything needed in the complete solution, such as structural elements, MEP, doors, windows and finishes. The rapid delivery time and flexibility in transferring the building for another purpose are the competitive advantages. The company's business model does not involve selling buildings but leasing them for 3 to 10 years. The producer takes full responsibility for the quality and maintenance of the buildings. At the end of the lease period, the building and its parts are leased to the next customer for another purpose. The building slices are easy to reconnect, using standard sectional interfaces. The estimated life cycle of the modules is at least 20 years, and around a quarter of all the company's modules are at least on their second use cycle.

Table 2 summarizes each case's characteristics. Simplified figures are used to highlight the modularization in the cases, the components, their interfaces and roles in the whole building. The characteristics follow the key concepts presented in the theoretical framework – objectives in their priority order, organization form, product architecture (including production system) and used platform assets. The last column presents whether each case's evidence supports one or several of the three propositions presented based on the theory. The table shows that each case has several objectives and how at least some of them are related to the project-phase performance – schedule, quality and

costs. In the organization forms, both collaborative forms of project actors and module suppliers and integrations of module production and project development exist in project organization-driven and supplier-driven strategies.

According to the analysis, seven of the nine cases replicate the propositions. In these cases, the combination of objectives, organization, product architecture and use of platform assets is aligned with the theoretical framework. Two cases only partly replicate the propositions. Case C represents an industry-driven modularization strategy, with the project organization's limited possibility to modify the building. Case G exemplifies a more supplier-driven strategy than the system's objectives and product architecture would assume. Equally noteworthy, most of the cases replicate P2; only Cases F and I fully replicate P1 and P3, respectively. These findings indicate that although modularization enables innovative design and flexibility, it is still mostly considered a solution to improve project-phase performance through preassembled modules and components.

#### 4.2. Challenges in modularization

The challenges of each case were analysed to obtain a realistic picture of each modularization strategy and to determine whether some adopted strategies did not optimally achieve the intended outcomes (Table 3). The strategies were named according to the organizing form as it reflected the modularization's objectives, and many of the challenges also originated from the relationships between organizations.

Project organization-driven strategies tended to have problems in establishing the performance aimed in the early phase of installations. In the hotel case E, the lack of existing knowledge and other platform assets set high requirements for learning among project actors, especially in the management of bathroom interfaces and assembly work onsite. Therefore, a project organization-driven strategy seemed appropriate only if the innovative design solution was utilized in a multitude of repetitive spaces, such as hotel bathrooms and hospital rooms. In Cases F and E, it was not evident which actor, if any, utilized the developed solutions as competitive assets for future projects. Designers' comments on hospital case F indicated that they were willing to replicate the solution in other projects; however, it was too early to evaluate this tendency's practical potential.

The collaborative strategy, in which a specific supplier designed and delivered the building, together with the project customer and the designers, encountered problems in defining and managing interfaces with subsystems, similar to the experience in the project-driven strategy. This problem was evident in the case A (façade producer),

where the interfaces between concrete structure and façade panels usually generate new acoustic and thermal issues, requiring additional processes (e.g. joint treatments and acoustic barriers) and tasks during assembling phase. In addition, case D (bathroom producer) required special attention with the interface between hydraulic installations and the prefabricated bathrooms. In the case B (concrete wall system) and D (bathroom producer), it was also unclear how scale advantages in component production could be gained if the design solution varied from project to project. In hospital case H, real collaboration was even challenged due to the inherent competition between project contractors and component suppliers. One developer company (Case B) solved the problem by having its own module factories. However, this strategy would require a high volume to cover the investment costs and to maintain the required capacity utilization in offsite operations.

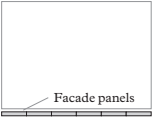
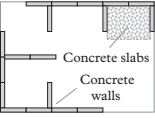
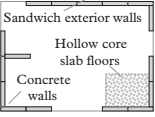
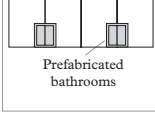
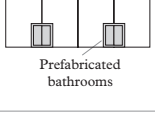
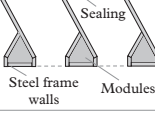
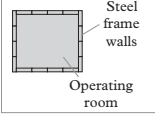
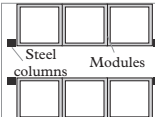
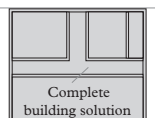
Supplier-driven strategies had fewer challenges in the delivery of building components and the management of interfaces than other, more project-driven strategies. Instead, all the investigated cases in this category revealed that the management and fulfilment of end users' expectations pose real challenges. Even if the building is perceived as having fine quality in the end, end users may complain about the poor image of modular buildings and the users' lack of involvement in the design phase. That was especially evident in case I in which the rapid purchasing and delivery process did not enable taking health care professionals' opinions into account. This finding is partly conflicting as the supplier-driven strategy generally enables flexibility in the building's use. Therefore, it seems that a trade-off in modularization strategies exists between a project organization-driven strategy that aims at a customer-oriented new building and a supplier-driven strategy whose goal is a more standardized building in the beginning but which can be easily modified during the use phase. Case G also indicated that adopting a supplier-driven strategy only in a small part of a building, such as in operating rooms, might be very complicated, especially if the supplier's assembly work was performed mostly onsite and significantly affected the schedule of activities in other parts of the building.

#### 5. Discussion

We began this paper with the assertion that modularization has been perceived as an appealing approach to improve efficiency, flow and quality in the construction industry (Gibb 1999, Lawson *et al.* 2012), but more knowledge is needed to understand how to apply modularization to achieve different objectives of building investments. Based on the literature review and the findings of the multiple case studies, modularization strategies can



**Table 2.** Summary of the modularization strategies of the cases.

Case	Objectives	Organization	Product architecture	Production system	Platform assets	Support for propositions
 <p>A</p>	(1)Quality (2)Schedule (3)Maintenance	Collaborative	Partially modular Bus/sectional interfaces	Non-volumetric preassembly	People, knowl- edge, processes	Yes (P2)
 <p>B</p>	(1)Cost-efficiency (2)Schedule	Integrated	Almost completely modular Sectional interfaces	Non-volumetric preassembly	People, knowl- edge, processes, components	Yes (P2)
 <p>C</p>	(1)Cost-efficiency (2)Supply chain flexibility (3)Schedule	Supplier(s)-driven	Almost completely modular Sectional interfaces	Non-volumetric preassembly	Knowledge, processes, compo- nents	Partly (P2); Indus- try-driven system
 <p>D</p>	(1)Quality (2)Onsite labour costs	Collaborative	Partially modular Bus interfaces	Volumetric preas- sembly	People, knowl- edge, processes	Yes (P2)
 <p>E</p>	(1)Quality (2)Schedule (3)Innovativeness	Project organi- zation-driven (design)/collabo- rative (delivery)	Partially modular Bus interfaces	Volumetric preas- sembly	People, knowl- edge, processes	Yes (P1 and P2)
 <p>F</p>	(1)Innovativeness (2)Quality (3)Schedule (4)Labour costs	Project organiza- tion-driven	Partially modular Bus interfaces	Volumetric and non-volumetric preassembly	People, knowledge	Yes (P1)
 <p>G</p>	(1)Quality (2)Schedule (3)Maintenance	Supplier-driven	Partially modular Slot/sectional interfaces	Non-volumetric preassembly	People, knowl- edge, processes, components	Partly (P2 and P3); more supplier driv- en than objectives and product archi- tecture assume
 <p>H</p>	(1)Schedule (2)Access to skilled labour	Collaborative	Completely mod- ular Sectional interfaces	Modular buildings	People, knowl- edge, processes	Yes (P2)
 <p>I</p>	(1)Flexibility in use (2)Schedule (3)Quality	Supplier-driven	Completely mod- ular Sectional interfaces	Modular buildings	Processes, compo- nents	Yes (P3)

have several manifestations in the construction industry context. Buildings are modular by nature as they are traditionally built from smaller subsystems that are designed and produced independently (Baldwin and Clark 1997). Therefore, to make a reasonable distinction between modular and traditional construction, we explained that in modularization, structuring the building in modules occurs at least in one part of the building. In modules, some functions (that in the traditional approach are integrated into the building onsite) are prepackaged, and these modules' interfaces with the building structure are loose and standardized. This definition follows the original

idea of reasonable "function sharing" at the component level (Voordijk *et al.* 2006). It differs from the concept of preassembly because modularization does not necessarily move assembly work offsite, but it primarily prepackages functions into a component in a new way that provides advantages to the building investment.

Understanding the different dimensions of modularization activities, their interconnections and possibilities to achieve various objectives would help practitioners select the modularization strategies that are appropriate for their specific context. The modularization concept is applicable, not only in describing different product architectures but

**Table 3.** Identified challenges in modularization.

Case	Modularization strategy	Identified challenges
(A) Prefabricated façade producer	Collaborative	Interfaces among subsystems (structure, masonry, windows, etc.) Specialized labour Few market options available Performance must be evaluated in multiple-storey buildings
(B) Prefabricated concrete wall system	Integrated	Guarantee of economy of scale (typical building project life cycle of 48 months, excluding maintenance) Specialized labour Customer rejection
(C) Prefabricated concrete element system	Supplier(s)-driven	Definition of standard details and connections Lack of competition among modularized systems Lack of innovativeness as product architecture is locked
(D) Bathroom producer	Collaborative	Guarantee of economy of scale Transportation costs Management of interfaces with subsystems
(E) Hotel project	Project organization-driven (design)/collaborative (delivery)	Management of assembly work and interface tolerances Learning diminishes performance in first few installations Module provider did not participate early enough in design Seismic connections were overlooked
(F) Hospital project	Project organization-driven	Interfaces among subsystems Necessity of first-run prototypes
(G) Hospital operating room producer	Supplier-driven	Needs both trade and location-based division of procurement Management of customer expectations in design
(H) Hospital project	Collaborative	Management of heavy equipment Relationship between general contractor and module supplier
(I) Modular building system producer	Supplier-driven	High company investment in the beginning Customer rejection due to poor image of modular solutions

also in explaining the structures of organizations and processes in designing and manufacturing products (Baldwin and Clark 1997, Fine 1998, Kusiak 2002, Salvador *et al.* 2002, Arnheiter and Harren 2005). Therefore, the dimensions of the modularization strategies identified in this research also cover product architecture, organization, production system and capability or asset aspects. In other words, a modularization strategy coherently answers who the actors are, what they do to the product architecture and which assets and processes they use during the building investment life cycle.

The developed theoretical framework presented how the dimensions of modularization strategies could and should be aligned with the main objectives of modularization. The framework suggested three strategies, as follows: (1) a project organization-driven strategy to enable innovative design solutions, (2) a prefabrication- and preassembly driven strategy to reduce costs and improve quality and time performance in construction and (3) a supplier-driven strategy to enable flexibility in use and maintenance. The analysed cases mostly supported the suggested propositions but also enabled the elaboration of the framework. Both collaborative and integrated organizing forms were found to exist to improve the performance of the construction phase through modularization. These different organizing forms can be understood as different ways of transferring value (Doran *et al.* 2007) in the construction supply chain. Collaboration among the project owner, designers and module suppliers transfers value from the contractor to other stakeholders, especially the suppliers. The integrated form instead ensures that the

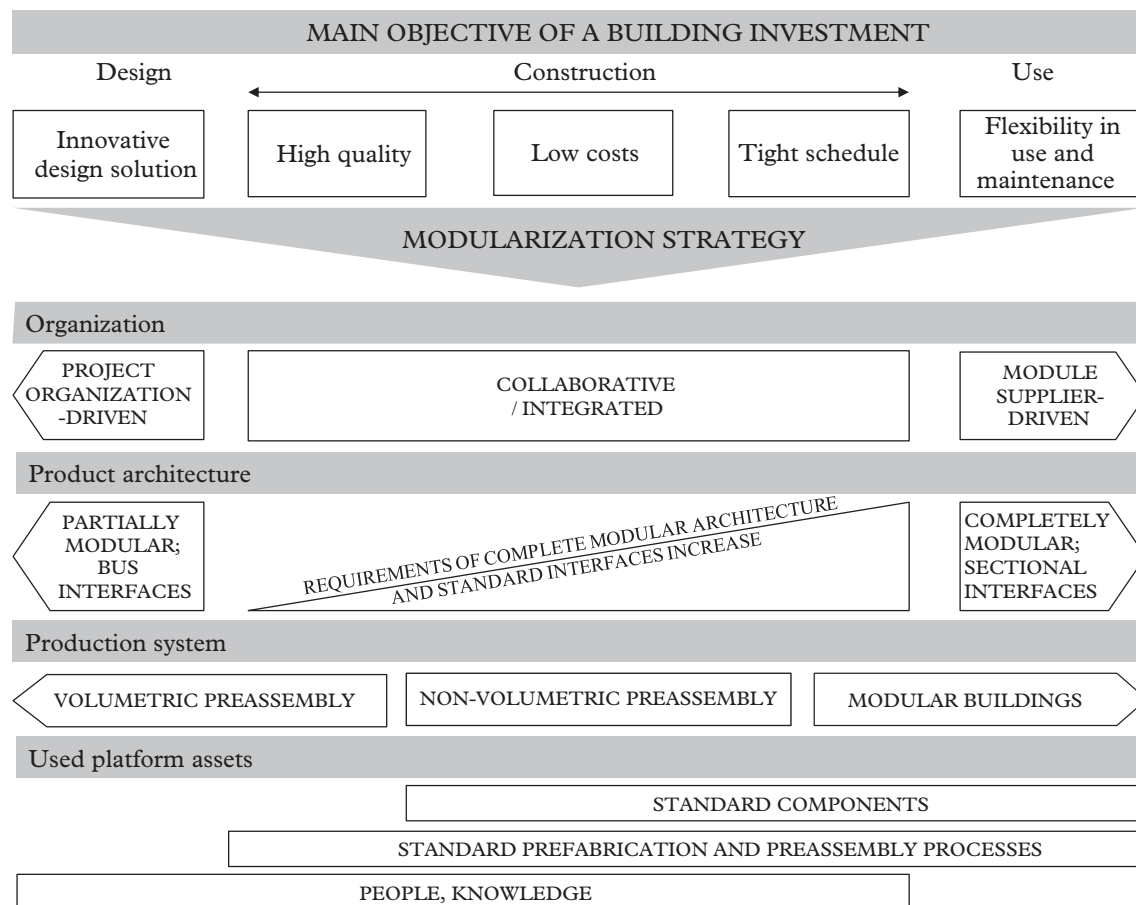
developer captures the final value despite the used production system.

Figure 3 presents the final framework of the modularization strategies, which summarizes the theoretical framework and the findings of the empirical study. In addition to the distinction between innovation- and flexibility-aimed strategies, the framework also differentiates among quality-, cost- and schedule-initiated modularization strategies. Cases A, D, E and G reveal that if high quality is the main objective, a partially modular product architecture in which a critical space of the building is prefabricated and preassembled as a volumetric module may be an appropriate strategy. On the other hand, if a tight schedule is the first priority to drive the decomposition of a building into modules (Case H), the most appropriate strategy is to utilize a more complete modular building – an approach with sectional interfaces that minimize the onsite work. Finally, if a lower cost is the main objective (Cases B and C), an industrialized production system with a non-volumetric preassembly of the most critical elements of the building may be a better strategy. Volumetric components are expensive to transport and move. Therefore, in preassembly, focusing only on non-volumetric elements, such as exterior walls, is a suitable strategy for better cost-efficiency. The framework also emphasizes that the use of standard components supports flexibility, a tight schedule and low costs as it enables component replacements, scale economy and a shortened design time. If a component design needs to be customized, the use of standardized prefabrication and preassembly processes can still improve the

project-phase performance. However, professional people and knowledge are needed to configure the product architecture and production system for the specific needs of the building investment.

The practical aim of this research is to increase the understanding about appropriate modularization strategies in building investments. This study has two significant implications, particularly for project managers who make decisions about the use of modularization in building investments. First, it underlines the importance of understanding different objectives of building investments and their connection to the appropriate modularization strategy. Owners, designers and developers could use the framework when they specify to what extent modules could be employed in their investments, what kind of organizing form would best support the modularization effort, and what would be the most suitable production system. In the early phases of the project, decision-makers should be open to innovative methods and select the strategy that best fulfils their innovation, cost, schedule, quality and flexibility targets for the building and the project.

Second, as modular products become more popular in construction, traditional actors should reassess their roles in supply chains, considering both potential threats to their current businesses and new opportunities that modularization provides. To strengthen their future functions in the industry, designers, contractors and labour and material suppliers can make strategic decisions to develop a new role in the supply chain. According to our framework, the roles can be, among others, the service provider helping customers decide their modularization strategy in the early phase of the project, the solution owner who aims at leveraging the standardized design or product in several customer projects or the contractor who specializes in preassembly processes and logistics management. Modularization also enables more networked and partnership-based business models, thus creating space for solution providers that can manage the whole supply chain and provide more comprehensive solutions to customers. The significance of flexibility in building use and maintenance is emerging, meaning that whatever new role an actor assumes, its modular offering should support the building's life cycle performance.



**Figure 3.** A framework for classifying modularization strategies according to the main objectives of building investments.

## 6. Conclusions

This research has attempted to identify the dimensions of modularization strategies in the construction industry and to determine the ways that various modularization strategies achieve different objectives of the building investments. The developed framework and empirical findings contribute to existing knowledge on modularization in construction in three ways.

First, to our best knowledge, this study is the first attempt to define modularization strategies in construction and to categorize them according to their intended objectives in building investments. The developed framework explains how modularization strategies differ in terms of their organization, product architecture and use of platforms. The framework highlights the existence of project organization-driven, supplier-driven and collaborative and integrated organizing forms of modularization. Since earlier research has shown that modularization changes supplier relationships, ranging from integrated to non-integrated (Hofman *et al.* 2009), this study takes a building investment approach and argues that even supplier-driven modularization could be suggested, which means a remarkable shift in power and value from project organization to module supplier. If modularization is aimed at remarkable improvements in project schedule or flexibility in use and maintenance, collaborative work between designers and site operators (Gosling *et al.* 2016) is not necessarily enough. Larger roles should be assigned to the module supplier and the use of standard components.

Second, when theoretical foundations of product modularity are applied, the study points out how modularization can offer a solution to several management objectives of building investments that goes beyond project performance measured in terms of cost, time and quality. The theory of modular product architecture and existing cases has been used to show how modularization enables innovative design solutions and flexibility in building use and maintenance. This research distinguishes between modularization and strategies that aim at industrialization (Jonsson and Rudberg 2014) or preassembly (Gibb and Isack 2003) by arguing that even if the concepts are highly interconnected, industrial preassembly is not necessarily essential in modularization. Modularization can be used to separate a specific part of a building for a dedicated design team to increase innovativeness, or it can focus on developing standards and loose interfaces, which enable later modifications. These strategies are not always connected to preassembly although in practice, structuring the building in modules also supports their preassembly. The aim to increase preassembly, inherent quality and

schedule performance can be a factor leading to modularization. However, it can also be a secondary issue if the main objective is related to innovation or flexibility in use and maintenance.

Third, the research presents definitions of module, modularization and modularization strategy in construction, based on the theory of modular product architecture (Ulrich 1995), platform assets (Robertson and Ulrich 1998, Thuesen and Hvam 2011), production strategies (Skinner 1985) and their adoptions in construction (Miller and Elgård 1998, Voordijk *et al.* 2006, Jensen *et al.* 2012, Jonsson and Rudberg 2014, Gosling *et al.* 2016). While the used definitions of module and modularization follow those of earlier research, the definition of modularization strategy combines the concepts of product architecture, platform asset and production strategy in a new way, making the implementation of modularization at a building investment level more concrete and understandable. As earlier studies on strategic management argue that product structure designs organizations (Sanchez and Mahoney 1996) and supply chains (Baldwin 2008), this study emphasizes that modularization shapes the roles and boundaries between the firms in the construction supply chain and that the suitable organizing form depends on what kinds of product architecture and platform assets are needed to achieve the intended outcomes of modularization.

The present study has investigated the dimensions of modularization strategies and the connections between the strategies and different objectives of building investments through a review of theories and concepts related to modularization and an analysis of nine cases of existing modularization strategies. Therefore, our study is partly limited by the choice of the cases and their characteristics. One limitation is that all contextual factors of the cases and regions, such as cultural, geographic and competitive conditions (Poulis *et al.* 2013), were not fully considered in the analysis. Despite the cases' variety in their main objectives, modularization strategies and countries, our results can be generalized only at the theoretical level through the framework and formulated propositions. The framework could be assessed by hypothesis-testing empirical research on other cases and in other countries. Horizontal integration and cooperation as organizing forms are relevant issues for further exploration. There is also space for research about modularization related to innovative design solutions and flexibility in use and maintenance since such cases represent the minority in our empirical research. Therefore, we recommend future research in different contextual settings to test our framework, as well as more in-depth quantitative research to identify the connections between modularization strategies and their justified outcomes in building investments.



## Disclosure statement

No potential conflict of interest was reported by the authors.

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