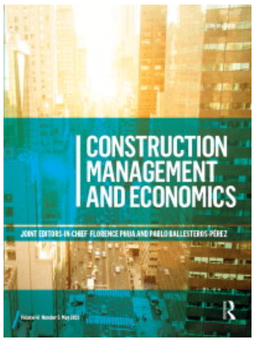

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How the reliability of external competences shapes the modularization strategies of industrialized construction firms

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ABSTRACT
Firms modularize as they move into industrialized construction. Prior research highlights the importance of their modularization strategies, arguing that firms can either build the competence for modularization internally or can source them externally. To understand what shapes a firm's choice to use external competences in its modularization strategy, we studied three leading construction firms. In this multiple case study, Alpha, Beta and Gamma are leaders in Asian markets, using reinforced concrete solutions in high-rise industrialized construction. Where external competences are available, our analyses show the work firms do to make them reliable and that their choice to use external competences is shaped by their reliability. Alpha modularized in a context with little available external competences, so it built new competences in-house; Beta chose to use the externally available manufacturing and assembly competences, using standards, remote monitoring and control of product architectures to make them reliable for their use in modularization; Gamma had available competences in the external context and initially sought to use them, but reliability concerns led to it modularizing by acquiring the firms to bring these competences in-house. Our contribution is to show how ensuring the reliability of external competences shapes modularization strategies. Further, we have identified actions that firms can adopt to make external competences reliable through: (1) use of international standards, (2) quality control procedures, (3) control of product architectures, and 4) acquisition of external competences. We provide implications for practitioners and policy makers seeking to transition to industrialized construction; and discuss new areas for research.

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Introduction

To make the transition into industrialized construction and improve productivity in the delivery of buildings and infrastructure, firms must modularize their building systems so that they can be manufactured and assembled in a controlled environment (e.g. Gann 1996, Barlow *et al.* 2003, Glass *et al.* 2022). Firm modularization strategies set out how they will develop and deliver these modular product architectures (e.g. Pan *et al.* 2012, Pan and Goodier 2012, Lessing and Brege 2018, Shafiee *et al.* 2020). These modularization strategies are dependent on firm capabilities, which are built through competences that can be both internal or external to the firm (Brege *et al.* 2014, Lessing and Brege 2018, Teece, Pisano, and Shuen 1997). Previous studies have explored the relationship between modularization strategies and supply chain relationships (Doran and Giannakis 2011, Jones *et al.* 2021). Yet extant work has not examined what shapes a firm's choice to use external competences in its modularization strategy.

External competences can be important as modular product architectures allow firms to set out standard interface specifications (Sanchez and Mahoney 1996) and adopt externally supplied components (Baldwin and Clark 1997). Defining competences as the skill sets that need to be sourced and combined by the firm to build new capabilities (Teece *et al.* 1997, Helfat and Peteraf 2009, Davies *et al.* 2016), scholars that draw on a knowledge-based perspective argue that success of inter-firm modular projects relies on technological competences, and firms' repertoire of capabilities (Brusoni *et al.* 2001, Campagnolo and Camuffo 2010).

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In this literature, such competences can be built within firm boundaries or acquired externally (Tee 2019, Tee *et al*. 2019) as firms coordinate with other firms (e.g. suppliers) to modularize (Brusoni *et al.* 2001, Campagnolo and Camuffo 2010).

We use a multiple case study of three leading construction firms that are transitioning to industrialized construction to address the question: *What shapes a firm's choice to use external competences in its modularization strategy?* Such choice is of crucial importance, where firm strategies are understood to be concerned with developing unique combinations of competences and capabilities that are durable, difficult to imitate and difficult to transfer (Prahalad and Hamel 1990). Suprisingly, our study suggests that the choices that construction firms make to use external competences to modularize are shaped by the reliability, as well as the availability, of these competences. We found that Alpha modularized in a context with little available external competences, so it built new competences in-house; Beta had to adopt strategy choices to make the externally available manufacturing and assembly competences reliable; Gamma had available competences in the external context, but it could not make them reliable, so it modularized by acquiring firms and building competences in-house.

The next section situates our empirical study in relation to the growing literatures on modularization strategies in industrialized construction. The following section describes the case study methods and analyses. The finding section provides detailed analyses of the three firms, Alpha, Beta and Gamma, explaining their strategy choices to exploit and make the external competences reliable for their modularization strategies. In the discussion and conclusion sections, we report our theoretical contribution and explore the implications for practitioners and policy makers seeking to transition into industrialized construction.

Theoretical background: modularization strategies in industrialized construction

Modularization is strongly associated with industrialized construction, where modern manufacturing methods become used to fabricate and assemble materials (Gibb 1999, Brege *et al.* 2014). Modularity allows firms to de-couple both the design and manufacturing of components that constitute a product; and ensure the integration of externally supplied components into the final product architecture (Baldwin and Clark 1997, Aversa *et al.* 2015, Brusoni *et al.* 2023). In other words, modularity refers to the way in which a product (e.g. buildings, infrastructure) design is decomposed into different parts or modules.

In construction, a module defines a unit that is designed and manufactured, ready for onsite assembly with predefined interfaces (Gibb and Pendlebury 2006, Gosling *et al.* 2016, Peltokorpi *et al.* 2018), with firms seeking to develop a set of modules that can be reconfigured, known as a "kit of parts". The degree to which the product architecture is modularized, and the nature of that modularization, can vary, from simple component manufacture and sub-assembly to non-volumetric preassembly, volumetric preassembly or fully modular buildings (Gibb 1999, Gibb and Isack 2003, Pan *et al.* 2012).

However, it is the competences, more than the product architectures, that are a focus in work on modularization strategies. While Sanchez and Mahoney (1996) argue that, to some extent, technical interdependences mirror organizational relationships, for authors such as Zirpoli and Camuffo (2009) it is the accumulated technological competences, repertoire of capabilities and coordination mechanisms rather than the product architecture per se, that explain the success of inter-firm modular projects. Through mobilizing competences, firms can engage in activities, such as taking *"raw materials and sub-assemblies and transforming them into physical components and subsystems that are manufactured to meet an overall system design"* (Davies 2004, p. 737).

Building on previous studies (e.g. Brusoni *et al.* 2001, Brusoni and Prencipe 2001, Davies 2004), we identified a range of competences required for modularization. At the subsystem level, these are design, manufacturing and assembly competences:

1. *Design competences*, related to the detailed design or redesign of modules without changing the interfaces through which they connect into wider systems;
2. *Manufacturing competences*, which refer to technical skill sets required for manufacturing modules, which can happen onsite or offsite in a controlled environment;
3. *Assembly competences*, which refer to the technical skill sets required for the final onsite assembly of modules into systems. They are different from the manufacturing competence, which can be owned by separate "suppliers" or "manufacturers" (Brusoni *et al.* 2001).

For decomposing and integrating modules at the system level we also identify *decomposition* *competences*, related to the "conceptual design" or "schematic design" of building systems (Brusoni and Prencipe 2001, p. 195), which are the technical skill sets for decomposing the building systems into modules; and *integration competences*, which refer to the technical skill sets for integrating components and modules into the finished building systems (Davies 2004, p.737).

Within the growing literature on modularization in construction (e.g. Jensen *et al.* 2012, Pan and Goodier 2012, Shafiee *et al.* 2020), there is attention to the role of government policy in shaping modularization (Oti-Sarpong *et al.* 2022) and also to how modularizing can change inter-firm relationships. Doran and Giannakis (2011) argue that modular product architectures can be complemented with a high-level supply chain and process integration. Jonsson and Rudberg (2014, 2015) suggest that different forms of modularity can be located across two axes, where one is the degree of offsite production (with higher productivity associated with less flexibility), and the other is the degree of product standardization and volumes. In a detailed study of the matching between product architectures and contractor–supplier relationships in industrialized construction, Hofman *et al.* (2009) find alignment not only contingent on variety in customer demand, but also intentions of contractors and suppliers, the investment of suppliers, and the dependence of the firm on their knowledge. Research has also examined how knowledge and task structures enable (or inhibit) systemic innovation across the industry (see e.g. Hall *et al.* 2019, Jones *et al.* 2021, Glass *et al.* 2022).

These studies have advanced our understanding of the relationship between modularization strategies and the firms' external contexts, supply chain relationships, and the degree of product standardization. While there is substantial work on modularization strategies from a knowledge-based perspective, with a focus on competences, in the wider literature (Brusoni *et al.* 2001, Brusoni and Prencipe 2001), this is relatively under-explored in the construction context. To contribute to this perspective, we build on Brege *et al.* (2014); and Lessing and Brege (2018), who draw on Teece *et al.* (1997) to recognize the importance of both internal and external competences as well as surrounding contexts in shaping firm's modularization strategies. Their work implies a fit between firm competences (both internal and external) and requirements of a target market. Yet Lessing and Brege (2018) describe the knowledge-based perspective as used instrumentally by the firm, rather than themselves using the theory to explain the actions of the firm. They contrast a firm with an "inside out" approach, in which they locate the concerns with the use of internal and external competences, to one with an "outside-in" approach, which gives more focus to the important connections with the market and customers. Thus, while these authors provide one of the first explorative studies of how internal and external competences can be used to achieve modularization, their analyses are limited to the fit between firm competences and requirements of a target market, which provides little explanation of why firms choose to use internal or external competences. From a knowledge-based perspective, we need a better understanding of what shapes a firm's choice to use external competences to modularize. We aim to shed light on such choices through a multiple case study. In the next section, we report our research design and data anaysis process.

Research method

The research was designed as a multiple-case study of three leading industrialized construction firms. Unlike different research approaches (e.g. survey research), this method uses a replication logic and treats each case as an "experiment", making it applicable to studying a phenomenon in context, where there are unclear boundaries between the phenomenon and context (Yin 2003, Eisenhardt and Graebner 2007). It has become widely used to explain the complex phenomena emerging in construction practice (e.g. Blismas *et al.* 2004, Pan and Pan 2019), with construction scholars advised to use their cases to build models, seeking depth in terms of theoretical and literal replication and paying attention to dynamics and multiplicity emerging within and across their cases (Taylor *et al.* 2011). A multiple case study is an appropriate method for this study as it enables both an in-depth contextual analysis of the modularization strategy of each firm using data from the field and the comparison and contrast of the different choices made by these firms over time in relation to the contexts in which they operate.

Case selection

We conducted the empirical study in Asia. The cases are well known as leading industrialized construction firms. They were selected from a wider set of potential cases by identifying construction firms that are recognized as leading in their market; and using a modular kit of parts (or product library) in their construction. To identify comparable cases, we limited the scope to the leading firms engaged in high-rise industrialized construction (using reinforced concrete) as this style of construction is common in Asia. In this way, we aimed for literal replication in these dimensions by looking at the same type of construction firms to replicate our findings across them (Yin 2003). While having many features in common, one difference between the firms is that they have different external contexts, each operating in a different jurisdiction in Asia. This is highly appropriate to the question we ask in this paper, as it provides variation along a theoretically relevant dimension. Table 1 gives an overview of the three case study firms that we studied.

The governments in mainland China, Hong Kong, and Singapore have launched direct or indirect incentives to promote the adoption of modularization and industrialized construction, such as industrialized and prefabricated building in mainland China (MOHURD 2017); Modular integrated Construction (MiC) in Hong Kong (DEVB 2020) and Prefabricated Prefinished Volumetric Construction (PPVC) and Design for Manufacture and Assembly (DfMA) in Singapore (BCA 2020). The variability across jurisdictions means the cases have distinctive external contexts, while we recognize that there are similarities across cases in that each of these firms operates in a context in which government policies support firms in modularizing and transitioning to industrialized construction.

Data collection and analysis

We started data collection once we received ethics approval, guided by a research protocol. The research protocol structured data collection from secondary and primary data around topics of interest: (1) Product platform definition; (2) Why the firm is changing to a product platform; (3) Risks behind product platforms; (4) Project delivery model; (5) Client/customer relationship; (6) Performance of digitally-enabled product platforms; (7) Degree of offsite construction; (8) Technologies and processes; (9) Predefinition; (10) Product architecture; (11) Interface; (12) Production systems; and (13) New product development. Table 2 summarizes the different sources of data collected on the three firms. Each case combines secondary data (e.g. archival material, firm websites, annual reports, official documents, slide decks, book chapters) with primary data (e.g. semi-structured and informal interviews and observations in firm and factory visits). As we collected and analysed data and became familiar with each case we became interested in the role of external competences, which was not well explained in previous work, and we focused further data collection on areas in which we did not have theoretical saturation.

As we analyzed the data, we triangulated data from multiple sources (Eisenhardt 1989), cross-checking primary data from interviews with the secondary data. As a first step, we wrote a descriptive case study report for each case, conducting within-case analyses before seeking to identify the similarities and differences across the cases (Miles *et al.* 2014). The narrative descriptions of the cases were circulated to three key informants in the associated case firms to check our interpretations. As we conducted the cross-case analyses, we continued engaging with the data and compared emerging findings with prior literature on modularization in construction. We categorized these competences as internal or external, and sought to understand what affected the firms' strategic choice to use internal or external competences. As we displayed and discussed the emergent findings, we also returned

Table 1. Backgrounds of leading construction firms studied.

Case code	Firm Alpha	Firm Beta	Firm Gamma
Headquarter location	China (mainland)	Hong Kong	Singapore
Recognition in the local industry	Grade-Special General Building Contractor, Grade-1 Building Design by MOHURD (2022) – the highest qualification	Registered Specialist Trade Contractor – Precast Concrete Component by CIC HK (2021) – the highest qualification	A1 grading under CW01 Grade (General Building) by BCA (2022) – the highest qualification
Geographical market(s)	China, Middle East, Japan	Hong Kong	Singapore, Southeast Asia
Modular kit of parts	*Non-volumetric preassemblies:* 8 types (integrated floors, internal walls, external walls, integrated kitchens and baths, elevators, integrated interior decoration systems, and intelligent building management systems)	*Non-volumetric preassemblies*: precast slab, façade, balcony; *volumetric preassemblies:* bathroom units; *Modular buildings:* modular integrated construction (MiC) module (plant room with interior fitting-out and MEP), housing module	*Non-volumetric preassemblies:* panel slab, hollow core slab; volumetric preassemblies: façade wall; prefabricated bathroom unit; *Modular buildings:* Prefabricated Prefinished Volumetric Construction (PPVC) housing module
Market segment(s)	Apartments, hotels, schools	Apartments	Apartments

Table 2. Data collection summary.

Sources	Details (duration; dates, collected documentation/research records)
Firm Alpha in mainland China	
Informal interviews (conducted in Chinese)	1. Deputy General Manager, 22 Jun 2019, 35 mins online, field notes
	2. General Manager, 24 Jul 2019, 35 mins online, field notes
Semi-structured interviews (conducted in Chinese)	3. General Manager of the Design Institute for R&D, 6 May 2020 (30 mins)
	4. Lead Structural Engineer and Lead Architect, 13 May 2020 (60 mins)
	5. Deputy General Manager of the Design Institute for R&D, 15 May 2020 (91 mins)
Documents	Book chapter: co-authored by the Deputy General Manager (contains firm background and supply chains) (20 pages)
	Annual reports, published publicly from 2009 to 2021 (over 2000 pages of operation, strategic and financial information)
	Slide decks: Digital solutions for industrialized construction (39 pages); Housing products and related development (49 pages); and Industrialized construction and project portfolio (34 pages)
	Technical specification for assembled partially-encased composite structures of steel and concrete
Videos	Video showing the firm's industrialized construction design, manufacturing and assembly (7 minutes 38 seconds)
	Video showing BIM-enabled industrialized construction workflow in a school project (2 minutes 35 seconds)
Firm Beta in Hong Kong	
Informal interviews	6. CEO and Director, 12 Jun 2019 (90 minutes), field notes (2 pages)
Semi-structured interviews	7. CEO, 15 May 2020 (80 minutes, online)
	8. Director, 11 May 2020 (50 minutes, phone interview)
Visit	Company visit, 12 Jun 2019, accompanied by CEO and Director
	Exhibition visit, 19 Dec 2019, accompanied by Director
Documents	Slide decks on Building systems and information management (supply chains, design, manufacturing, logistics and assembly) (50 pages); and on DfMA experience sharing (17 pages)
	Approved module drawings from the government website
Video	Technical details of their products and projects (1 minute 40 seconds)
Website	Detailed information on products and services, firm qualifications and project portfolios; and introduction and interview about this firm
Firm Gamma in Singapore	
Informal interviews	9. Digital innovation lead; Production planning engineer, 4 Jul 2019 (58 minutes, online), field notes
Semi-structured interviews	10. Digital innovation lead, 12 Sept 2019 (46 minutes, online)
	11. Technical Director (precast), 15 Oct 2020 (36 minutes, online)
Visit	Office and factory, 22 Oct 2019 (3 hours), 157 photos, field notes
Documents	Annual report, financial years 2013 to 2021 (968 pages); and sustainability reports, Financial years 2018 to 2021 (131 pages)
	Slide decks, introducing the company (28 pages); and Introduction of DfMA development in Singapore (35 pages)
	Company profile, profile of a firm acquired by Firm Gamma (20 pages)
Seminar	Webinar, DfMA and digital construction Webinar, 2 hours, notes
Website	Website, Interview with Digital innovation lead and production planning engineer by a third party, and website video, Introduction of its design and production workflow (3 minutes)

to our data to elaborate on and substantiate our analyses.

Findings

Our findings show how the reliability of external competences shape the modularization strategy of construction firms. We argue that to use available external competences firms need to be able to access them in a predictable and ongoing way, and that they do work to try to make these competences reliable. In our cases, Alpha modularized in an external context with relatively few available design, manufacturing and assembly competences, so it built new competences in-house; Beta modularized in an external context with available manufacturing and assembly competences, which it had to make them reliable to be used in modularization; Gamma also had available competences in the external context, but as these were found not to be reliable, it modularized by acquiring firms and building these competences in-house. To make external competences reliable, these construction firms needed to act (i.e. using international standards, quality control procedures, control of product architectures, acquiring external competences) and their success in achieving reliability affected their strategic choices as to whether to use needed competences that were available externally. In Figure 1 we summarize our findings, showing how where external competences are available actions are taken to make them reliable, and how modularization success is achieved in each case. We provide more details about each case in the following sub-sections.

Case Alpha: building internal competences

To develop a modularization strategy, Alpha had to invest and develop in-house competences in design,

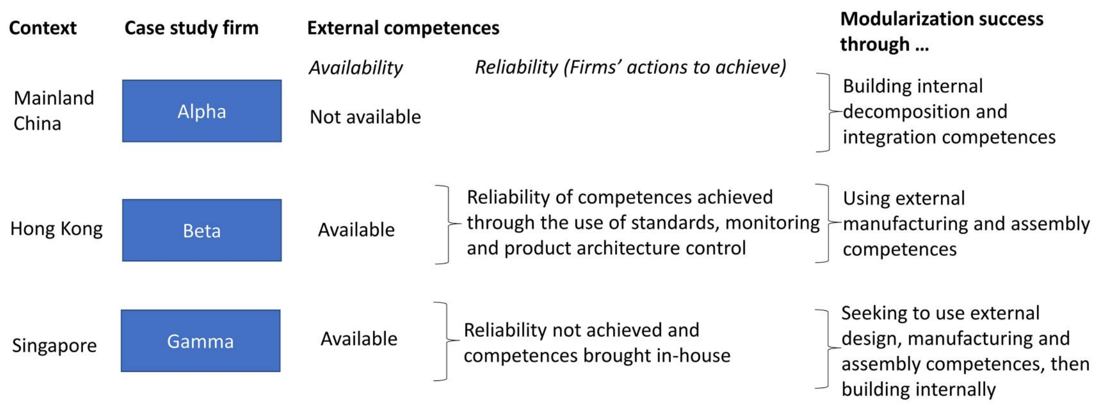

Figure 1. Overview of the findings.

manufacturing and assembly as it operated in a market with relatively little external competence in modularization. Based in mainland China, it started as a component specialist manufacturing firm and became one of China's largest multinational industrialized construction firms operating globally. It invested over 3% of annual revenue and employed 17% of staff in R&D (Annual Report 2011). It has a range of concrete-steel composite-based building systems for different market segments, including apartments, offices, schools, hospitals, and dormitories.

To modularize, Alpha sought to strengthen its design competence by developing proprietary product architectures and relevant subsystems (or modules) (Annual report, 2013), including, proprietary eight subsystems, which enabled hybrid configurations, and leveraged the advantages of steel as well as precast concrete structural framings. This system increased the prefabrication ratio from 50 to 95% (Annual report, 2018). As Alpha aimed to keep the leadership of the modular and prefabricated construction market, it invested a lot of its financial resources in developing new technologies. As it is reported in its 2010 annual report: *"We have either those (technologies) others do not possess, or better (technologies) than what others possess"*. This quote shows that over a substantial timeframe, Alpha has developed competitive advantages over its competitors by investing in modular and prefabricated technologies and developing the related competences (i.e. design, manufacturing and assembly).

Because there was a lack of available decomposition and integration competences, Alpha chose to develop these competences in-house for modularization. *"(We are) among the first pilot batch for Grade-1 general contracting*" (Annual report, 2015) – Alpha became a first mover, expanding the scope of the firm (vertically integrating) – "*building on our […] core technologies of eight subsystems we are in a leading position to further develop proprietary technologies [.] create technical barriers*" (Annual report, 2013). Its proprietary product architecture, as a result of research and development, enhanced its decomposition and integration competences, so that Alpha can control product architectures. Its 2020 annual report shows how the firm has now covered most of the value chain, from design and manufacturing to assembly on site and maintenance through life. It is no longer a component supplier and instead qualified with *"Grade-Special General Building Contractor"* and *"Grade-1 Building Design"* by the Ministry of Housing and Urban-Rural Development, the highest qualifications.

Although our analysis focuses on the reliability of the external competences, we found that Alpha used several approaches to increase the reliability of its internal manufacturing and assembly competences. Because of its concerns on quality, Alpha adopted lean production principles for *"quality assurance, timely delivery, cost control, safety management"* (Annual report, 2010). It arranged lean production training for production line staff and middle management (Annual report, 2010). Alpha also set up quality management systems for *"compliance monitoring in the whole manufacturing process"*, and *"defect monitoring of finished products"* (Annual report, 2016). As a recognition of its manufacturing and assembly competences, it won several national and provincial awards for excellence in quality control, which contributed to its reputation – allowing it to deliver not only high-rise housing but also some of the iconic projects, the National Stadium of the 2008 Olympics. It has implemented *"lean management"* and established digitally-enabled quality management systems to ensure the reliability of manufacturing and assembly competences.

Case Beta: making reliable external competences

Based in Hong Kong, Beta was a component specialist firm that modularized by leveraging external competences in design, manufacturing and assembly. In one of our interviews, the CEO confirmed that its modularization strategy relied on external manufacturing and assembly competences: *"I outsource our production works, our logistic work"* (CEO). Before Beta's modularization, it used internal design and external manufacturing competences – to design and manufacture by supplying modules, e.g. DeckBeta, with little control of product architectures. It developed DeckBeta as a component designer, and its CEO said, *"I started with the [DeckBeta] which I have a background with designing it as a structural engineer"*. Beta gained recognition by listing its product DeckBeta on *Construction Innovation and Technology Fund*'s pre-approval list. By focusing on designing and approval from the government funding of DeckBeta, Beta developed a strong design competence in designing components.

Apart from this design competence, modularization requires manufacturing and assembly competences; thus, Beta sought to use manufacturing and assembly competences by searching for these locally. Yet, it turned out there was no such factory in Hong Kong – *"there was no precast factory in Hong Kong"* (CEO). Beta then sought these competences in mainland China or Malaysia. Yet, this meant that Beta had to develop internal control procedures. As stated by the CEO: "*we're gonna impose you know radical process by nature […] it's not easy to find a suitable supply chain for any new product*" (CEO).

As the CEO mentioned, it is very important to have access to reliable manufacturing and assembly competences:*"(We) need a mature product supply chain (for manufacturing and assembly)"*. This is because manufacturing and assembly are considered as "*very hard to control […] (CEO).* In addition, as the CEO explained to us in one of the interviews: *Whether the production will be with good quality and on time, and whether the logistic will deliver just in time, everything and whether the onsite assembly team […] have the skillset to assemble or install [in a] right away" (CEO).* This quote from the CEO provide us with evidence that the modularization process requires that modules are delivered on time respecting quality requirements. From Beta's website, we noted that it worked closely with some assemblers to improve the reliability of their competences. To strengthen the reliability of external manufacturing and assembly competences, Beta imposed management standards and digitally-enabled quality management systems across manufacturers and assembler firms for monitoring and control purposes (Firm website and CEO)*;*

Beta, further, imposed standards to ensure the quality and reliability of external manufacturing and assembly competences. As the CEO reported to us: *"we impose our quality standard […] we have supervising officers to the production facilities to monitor assurance […] use our own lab testing equipment […] we provide remote monitoring devices to our transportation team" (CEO).* To do so, Beta had to take control of product architecture in an early stage – to allow modules to be pre-defined and integrated with Beta's modular product architectures (Buildings Department, 2022). Such pre-approval also ensured Beta's modules can be available in the supply chains. Because of the quality and time uncertainty in using external manufacturing and assembly competences, Beta realized these competences required higher reliability, and took steps to ensure that they could use these external competences.

Partnerships with external systems integrators and the adoption of standards and quality control procedures enabled Beta to influence the product architecture and access decomposition and integration competences. For example, to successfully adopt DeckBeta in a healthcare center project, Beta persuaded the main contractor and external consultants to change the product architectures of the building system. In another building project, Beta coordinated with the main contractor and other design consultants to change the original product architectures to modular. Although Beta made several successful attempts in projects, it had concerns on whether it could access such external competences continuously, *"we're gonna impose you know radical process by nature […] it's not easy to find a suitable supply chain for any new product"* (CEO). These concerns indicated that Beta faced uncertainties in sourcing and partnering with systems integrators who could always accept their products externally. Thus, to decompose and integrate building systems using its own modular product architectures, Beta needed reliable decomposition and integration competences at the systems level.

Beta developed these competences for decomposition and integration in-house, introducing a proprietary modular product architecture (a proprietary kit-of-parts), and listing this kit in the government pre-approval list. Because Beta can use its product architectures in modularizing most product architectures, it took control of product architectures in an early stage – modules can be pre-defined and integrated with Beta's modular product architectures.

Such pre-approval also ensured Beta's modules can be available in the supply chains.

These choices allowed Beta to be internationally qualified in quality, environmental and occupational health and safety management. It also became a Registered Specialist Trade Contractor (CIC HK, 2021). Its modular kit of parts gradually diversified with its projects.

Case Gamma: bringing available external competences in house to make them reliable

Based in Singapore, Gamma is a general contractor firm that encompasses design, manufacturing, and assembly competences for modularization by acquiring external manufacturing competences. Gamma is one of the leading general builders in Singapore with over than 40-year track record of building industrial, residential, and commercial facilities. It owns the highest qualification for building construction, *"A1 grading under CW01 Grade (General Building)"* by the Building and Construction Authority (BCA 2022). It provides *"a full spectrum of real estate services"* (Annual report, 2015), ranging from design and build, construction, turnkey construction, project management consultancy, procurement, and mechanical & electrical installation. Gamma has strategically allocated its manufacturing tasks to different locations, for example, volumetric modules were primarily produced in its Malaysian factory, while the local integrated construction precast hub was mainly responsible for component and non-volumetric modules (Digital innovation lead).

Gamma was initially a general builder. Moving towards modularization, it sought competences for design, manufacturing, and assembly as it had no such competences in-house. It started to screen those available design, manufacturing, and assembly competences externally. Yet, there were a few early-moving specialists with competences in detailed design, manufacturing, and assembly of modules externally, in which there were only four volumetric module specialists before 2016 (Government slide). One such specialist (invested by Gamma later), *PPVCSpecialist1* (pseudonym) developed a proprietary volumetric product platform in 2016, *"a Concrete PPVC System […] has been granted in-principle acceptance for use in building projects in Singapore, by the Building and Construction Authority (BCA)"* (Firm document). This was one of the early approved schemes by the government.

However, there were uncertainties about the reliability of these manufacturing and assembly competences across the national border, primarily due to political reasons. Gamma's Technical Director expressed the concern, *"their side (Malaysia) […] not have a good relationship […] so they try to impose something. […] impose a price or sometimes"*. Gamma had concerns about partnering with these external specialists for design, manufacturing, and assembly competences.

There were also uncertainties in the design competence due to a lack of control. Gamma's Technical Director noted the importance of controlling the design competence in-house:

> *in order to make that submission (approval in principle), you need to create your own PPVC (scheme) […] propose your connection detail and with all the production installation the whole activity.*

Gamma realized the necessity to have reliable competences in-house to carry out the detailed design of these PPVC modules. Its Technical Director noted, *"you know who cut the module then easy transportation control the width, control the lesson […] for the site handling"* (Technical Director). The reliable design competence was necessary, because Gamma needs to produce suitable and tight-tolerance design is important, especially to take transportation and onsite assembly requirements into the detailed design;

With concerns about the reliability of external design, manufacturing, or assembly competences, Gamma turned to establish a long-term cooperation with an early-moving module developer firm with such competences. It invested in *PPVCSpecialist1* (an early-moving module specialist who owned a BCA-approved PPVC scheme) and became a major shareholder. Its Executive director said, *"delighted to further strengthen our competences in modular construction through this cooperation (with PPVCSpecialist1)"* (Firm document). Yet, this cooperation did not allow Gamma to ensure reliable external competences. Therefore, Gamma had to establish its own competences by acquiring the 100% share of *PPVCSpecialist2* (pseudonym), *"complementing its (local manufacturing facilities) for precast concrete building components; including PPVC modules in Malaysia"* (Annual report, 2018).

Gamma also received the support from the government to construct an *"Integrated Construction Precast Hub"* with highly automated offsite manufacturing facilities for precast building components, through a government tender from Building Construction Authority (Annual report, 2015).

In addition to acquiring and establishing its own manufacturing facilities, Gamma regarded such internal manufacturing competence as a *"competitive advantage during the tendering process but also in the execution of construction projects"* (Annual report, 2018). It also enforced the quality management standards for these competences, in which *"obtained [...] ISO 9001:2015 certification for design, manufacture, and supply of precast concrete products"* (Sustainability report, 2019). All of these new measures further strengthened its control of quality on manufacturing and assembly so Gamma can use these competences in a predictable way.

The new acquired design, manufacturing and assembly competences have also been certified with qualifications as it is noted in its annual report: *"awarded the provisional certificates for the PBU Manufacturer Accreditation Scheme (MAS) and Prefabricated Mechanical, Electrical and Plumbing (MEP) Manufacturer"* (Annual report, 2020). Therefore, to make the design, manufacturing, and assembly competences reliable and exploit them for modularization, Gamma had to bring these competences in house to overcome the concerns about the external context.

Across cases

Our three cases of leading industrialized construction firms operate in contexts with different availability and reliability of external competences. Alpha had relatively little relevant external competences in its value chain, it therefore had to build and improve its own competences to modularize. However, the cases of Beta and Gamma are particularly interesting to explore our research question on how the reliability of external competences shape the modularization strategies of construction firms.

Beta sought to ensure predictable and ongoing access to competences by acting to continuously control the product architecture. In order to continue use external manufacturing and assembly competences in a predictable way, Beta monitored the manufacturing and assembly via digitally-enabled quality management systems, partnerships, and enforcing international standards across design and manufacturing.

Gamma similarly sought to ensure predictable and ongoing access to competences by acting to continuously control the product architecture, though there were remaining reliability concerns. As it achieved available but not reliable external competences, it acquired firms to bring the competences in-house.

Across these cases we find that to use external competences in modularization, construction firms not only need available internal or external competences but also need to make them reliable. External competences may become unusable where they are available, but unreliable. This unreliability may arise because of political risks, or as they become used by other firms in the context. Both Beta and Gamma had strategies to use external competences, though Gamma had to bring the competences in-house because it could not ensure reliable access to external competences. Thus, our analysis shows how the reliability of external competences shapes the modularization strategy of construction firms, and the choices they make to ensure the reliability of the competences.

Discussion: modularization and the reliability of competences

Our findings show that construction firms need access to reliable design, manufacturing, assembly, decomposition, and integration competences to modularize. As we discuss in this section, these findings extend prior work that identifies choices between internal and external competences (Brege *et al.* 2014, Lessing and Brege 2018, Hall *et al.* 2019) by showing how the reliability of competences shapes the modularization strategies.

They suggest it is not sufficient for modularization competences for design, manufacturing and assembly to be available externally. We identified four ways to ensure the reliability of the external competences. The first way is through the use of standards. We show that construction firms can apply internationally-recognized *standards* and become qualified in order to ensure the modules externally designed, manufactured, and assembled in compliance with the firms' requirements (e.g. Beta). The second is related to the *quality control procedures*. We found that quality control systems enable construction firms to assure the quality of products manufactured and assembled externally. The *control of product architectures* is the third way we identified. Construction firms can control the product architectures to decide and control how the modules can be designed, manufactured or assembled and to integrate following modular product architectures (e.g. Alpha, Beta). Last, acquisition is the fourth identified way to make reliable the external available resources. This way suggests that construction firms need to *acquire external competences* if they cannot ensure the reliability of external design, manufacturing and assembly competences due to the risks in their external environment (e.g. Gamma).

We further show that reliability is not a pre-existing property. For example, Beta implemented the use of international standards, remote monitoring, quality management systems to overcome the concerns with the subsystem level. With concerns on the reliability of such external competences due to the fluctuation of market requirements, we found that Gamma instead chose to acquire and bring the needed competences in-house.

To sum up, while previous studies (Brege *et al.* 2014, Lessing and Brege 2018) limited their analyses to the fit between firm competences and requirements of a target market, we extend these studies by showing that the choices that construction firms make to use external competences to modularize are shaped by their ability to ensure the reliability of the needed competences.

Our study also contributes to the work on systems integration (Prencipe 1997, Brusoni *et al.* 2001, Hobday and 2005, Whyte and Davies 2021). We found that none of the firms we studied were able to use external decomposition or integration competences to modularize. To control the product architecture, Alpha and Gamma developed decomposition and integration competences, while Beta had these competences in-house before modularization. We argue that this phenomenon is related to the power dynamics between the owner of the product architectures, clients or a systems integrator. For example, Alpha and Beta used "Design and Build" or "Engineering and Procurement and Construction", as a project delivery model, so that they can use in-house decomposition and integration competences to control the product architecture in a conceptual design stage. Gamma built the decomposition and integration competences. We also found that Beta was able to act as a systems integrator by bringing these competences in-house to gain value from external manufacturing and assembly competences, while the other two firms, Alpha and Gamma, become vertically integrated. Indeed, only Beta, successfully chose to use external competences in manufacturing and assembly, while Alpha and Gamma built their decomposition and integration competences in-house. Our findings also complement previous work on construction firms' strategies within a wider industrial context (Hall *et al.* 2019, Jones *et al.* 2021) by showing that where firms were able to access government funding, they could build new competences internally and develop long-term relationships with supply chain members to access reliable new external competences. Such reliable competences are key enablers of modularization strategies in industrialized construction.

Conclusions

The contribution of this paper is to show how reliability shapes firms' choices to use external competences in their modularization strategy. We answer the paper's theoretical question through analyses of a multiple case study of three firms, Alpha, Beta and Gamma, that are transitioning to industrialized construction. Our contribution extends the previous work on modularization and competences in construction by showing that the reliability of external competences shapes industrialized construction firms modularization strategies. We have identified four ways to make external competences reliable: (1) the use of international standards; (2) quality control procedures, (3) control of product architectures, and (4) acquisition of external competences. The reliability of competences needed to modularize is not a pre-existing property, and construction firms aim to make these competences reliable in a predictable and ongoing way.

Our study has implications for research. It extends the literature on internal and external competences in modularization (Brege *et al.* 2014, Lessing and Brege 2018, Hall *et al.* 2019). We agree with previous studies (Hall *et al.* 2019, Oti-Sarpong *et al.* 2022) on the importance of different external contexts for firms' strategies. We do acknowledge the limitation that the studied context and jurisdictions (i.e. Asia) aimed to promote the use of modularization and industrialized construction and in the delivery of social infrastructure, e.g. through government incentives or monetary mechanisms. Yet, as industrialized construction is becoming a crucial topic in the political agenda of Governments across the world, we believe that our study can inspire further research exploring how construction firms build or develop competences to modularize in contexts with less political incentives as well as those in which there is a policy driver that supports modularization. As we observe that Beta and Gamma had relatively stable demand from the social infrastructure as governments mandated the use of modular building systems, scholars could explore the role of the fluctuating demand in affecting the modularization strategy. Building on our contribution to understand the choices the firms make about using external competences in modularization strategies, future empirical research can include ethnographic studies to observe the transition to modularization. From our cases we observe there are changing relationships across the value chain, and these could be more fully unpacked in future studies to explore how, as firms make choices about how to use internal and external competences, firms also can make decisions about repositioning in the value chain, as they modularize and move towards industrialized construction.

Our study has implications for policy and practice. For example, it suggests that construction firms without in-house design, manufacturing or assembly competences can still embark on industrialized construction and capture value from it, where they can reliably source the competences they lack for modularization externally in the context within which they operate. Their ability to achieve this is also shaped by the firm's actions to make external competences reliable through the use of international standards, quality control procedures, control of product architectures, and acquisition of external competences. Beta shows one way that firms can use available external manufacturing and assembly competences and successfully manage to achieve reliable access to these competences. It does so by developing in-house decomposition and integration competences to enforce standards and control the product architecture. When firms lack internal competences, they should evaluate the availability and reliability of these competences externally in the value chain, and what they have to do to ensure ongoing access to reliable competences. This might include to bring these competences in-house or to implement appropriate quality controls.

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