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Openness and control in digitally-enabled construction platforms: a comparative case study of supply-chain strategies

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ABSTRACT

While product platforms in vertically-integrated firms are well studied, prior explanations become limited where platforming firms face tensions between openness and control in managing supply-chains. This paper explores how construction firms govern supply-chain interactions through digitally-enabled product platforms with varying interface openness. Drawing on a comparative case study of four firms, the research establishes that process embedding and process generativity serve as common foundational mechanisms required to bridge physical production constraints and digital workflows. Furthermore, the study provides new insight on process streamlining and process improvement as the distinctive control mechanisms used to dynamically adjust supply-chain governance. Depending on interface openness, firms configure proprietary or democratised process streamlining to control data flows and stakeholder workflows. Simultaneously, they deploy highly centralised or self-initiating process improvement loops to maintain authority over platform evolution. The paper extends platform governance theory from a physical-digital setting, by providing strategies to resolve the openness paradox and retain control over value creation.

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Introduction

In the pursuit of value creation, firms are increasingly substituting strict vertical integration with platform governance across their supply chains—a shift that is fundamentally changing how they innovate and compete (Cenamor and Frishammar 2021; Menon, Kärkkäinen, and Wuest 2020; Parker, Van Alstyne, and Jiang 2017; Tiwana, Konsynski, and Bush 2010). A key challenge for platforming firms is managing the tension between openness and control – they must provide sufficient autonomy to attract third-party innovation while maintaining enough control to ensure platform sustainability and value capture (Parker and Van Alstyne 2018). While this tension has been extensively studied in digital platforms like video games and mobile apps (Gawer and Cusumano 2014), we know relatively little about how it manifests in physical-digital contexts where digitally-enabled product platforms connect with physical production.

The construction industry provides a compelling context to examine this tension. Construction firms are increasingly adopting digitally-enabled product platforms to coordinate complex networks of suppliers, designers, and other stakeholders (Aksenova and Oti-Sarpong 2024; Hall, Whyte, and Lessing 2020; Jones et al. 2022). Unlike the transactional and project-centric supply chain governance traditionally examined in production and planning control (Bäckstrand and Fredriksson 2022; Cigolini et al. 2022; Gosling, Naim, and Towill 2013, Gosling et al. 2015; Gosling and Naim 2009), we need more granular understanding of how governance mechanisms operate when digitally-enabled product platforms intersect with physical production systems. These platforming firms in construction, acting as digital system integrators (Hall, Whyte, and Lessing 2020), maintain relatively stable core kit of parts and configurable design rules – *'a set of digitally-codified protocols, standards and specifications for product reconfiguration',* bridging physical production through digital interfaces (Zhou 2024). This creates unique challenges for balancing openness and control. Building on this, this study is motivated to examine how construction firms manage their stakeholders – including stakeholders of their supply chains – in open or closed product platforms.

Next, we summarise the relevant literature on platform governance and control strategy. Then, we detail our research design and present our findings on how platforming firms govern stakeholders within open and closed

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digitally-enabled product platforms. Finally, we conclude the article by highlighting our contribution to the literature and providing novel research opportunities and implications for scholars and managers.

Theoretical background

This study aims to explore how platforming firms govern stakeholders in the supply chains when open platforms up. Firms use new mechanisms to coordinate with supply chains in order to change the existing knowledge and industry structure, for example, through vertical integration, spin-off and digital systems integration (Hall, Whyte, and Lessing 2020).

Platforming firms in industrialized construction

Digitally-enabled product platforms are governed by digital systems integrators (platforming firms) with core modules in kits of parts and design rules interfacing with peripheral modules to enable scalable, adaptable project delivery (Jones et al. 2022; Zhou 2024). These platforms decouple entrenched knowledge structures (Ekanayake, Shen, and Kumaraswamy 2021) and reconfigure supply chains through digital systems integration (Hall, Whyte, and Lessing 2020). In the governance of such platforms, choosing the right openness degree is critical in deciding internal or external stakeholders in the supply chains. However, a tension arises: openness (to attract stakeholders for co-creation) versus control (to retain value and ensure compliance). Digitalisation of platforms amplifies this tension by enabling rapid product reconfiguration, which also creates more strategic challenges for platform governance (Sandberg, Holmström, and Lyytinen 2020). Thus, choosing whether to engage internal and external stakeholders for the delivery of core and peripheral modules is critical in shaping platforming firm's strategies (Aksenova and Oti-Sarpong 2024).

Supply-chain stakeholder dynamics in digitally-enabled product platform

Stakeholders are 'any group or individual who can affect or is affected by the achievement of a corporation's purpose' (Freeman, Harrison, and Wicks 2008, p. 6). We know stakeholders around product platforms are organised to 'compete and innovate' (Gawer 2014, p. 1244). These stakeholders can coordinate contractually (Gawer 2014, p. 1244) with examples such as automobile and aerospace platforms (Lampón, Cabanelas, and González-Benito 2017). As illustrated in Figure 1, these stakeholders fall into two primary categories: platforming firms and module developers. Platforming firms are defined as digital systems integrator firms that govern core modules in the kits of parts and design rules through digitally-enabled product platforms (Jones et al. 2022; Zhou 2024). Module developers are architects, contractors, manufacturers, or suppliers responsible for designing, producing, or assembling peripheral modules that interface with, but operate outside, the platform's core.

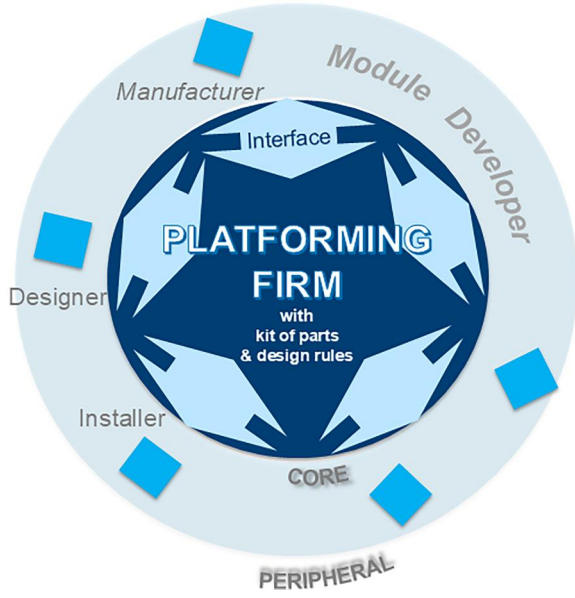

Figure 1. Platforming stakeholders dynamics.

Platform governance: Navigating the openness-control paradox

Platform governance hinges on resolving a fundamental tension: interface openness (sharing interface specifications to foster collaboration) versus control (retaining authority to protect value and ensure compliance) (Cenamor and Frishammar 2021; Jacobides, Cennamo, and Gawer 2018). Interface openness defines how platforming firms share the *'technical boundaries'* between modules (Gawer 2014, 2021),where these boundaries can be shared across a subset of firms, representing a relatively limited degree of openness, or across all firms, indicating a higher degree of openness (Gawer 2014). The degree of openness determines the extent of compatibility and exchangeability of interfaces (Chen and Liu 2005) and the number of stakeholders with access to interface specifications (Gawer 2014). Platforming firms must carefully balance the control and openness of platforms to manage stakeholder engagement while creating value (Boudreau 2017; Cenamor and Frishammar 2021).

Digital infrastructure, such as BIM models and automated workflows, amplifies this paradox that needs for openness and control. While these tools enable novel control mechanisms (Whyte and Lobo 2010). they also decentralise platform governance by distributing design rules and data across stakeholders (Hilbolling et al. 2020). For example, open interfaces may attract third-party innovators but risk platform fragmentation, whereas closed interfaces ensure stability but limit scalability (Menon, Kärkkäinen, and Wuest 2020).

In the context of digitally-enabled product platforms, the level of interface openness is determined by how extensively interface specifications are shared. In a platform with a relatively closed interface, the platforming firm may share interface specifications with multiple module developers. In a platform with a relatively open interface, the platforming firm may share interface specifications with multiple module developers and external platforming firms. This prompts us

to analyse construction firms' strategies for managing stakeholders and investigate the extent to which these firms exercise control over stakeholders when opening up their platform interfaces.

Process control mechanisms for platform governance

Platform governance require firms to balance control and openness when managing stakeholders (Boudreau 2017; Cenamor and Frishammar 2021). Drawing from platform governance literature, platform owners deploy formal and informal process control mechanisms to shape stakeholder behaviours while sustaining innovation (Jacobides, Cennamo, and Gawer 2018; Tiwana, Konsynski, and Bush 2010). Control mechanisms in open product platforms are more complex compared to those with internal product platforms (Thomas, Autio, and Gann 2014). These mechanisms represent how platforming firms exert influence on their module developers and other stakeholders to generate favourable behaviours (Tiwana, Konsynski, and Bush 2010; Yoo, Henfridsson, and Lyytinen 2010).

Platforming firms may manage stakeholders through the *process control* mechanism, in which the platforming firm dominates *'methods and procedures'* to manage and govern the platforms (Tiwana 2008; Tiwana, Konsynski, and Bush 2010, p. 680). In pure digital platforms, two key process control mechanisms are process embedding and process generativity (see Table 1). Process embedding enables platforming firms to manage different stakeholders with complex relationships (Hilbolling et al. 2020). Alternatively, platforming stakeholders can seek to embed digital skillsets into physical products, such as digital communication (Yoo, Henfridsson, and Lyytinen 2010, p. 725). Generativity control is another process control mechanism, which denotes that platforming firms control their stakeholders by controlling the capacity to generate complementary innovations such as new digital services (Chowdhury, Åkesson, and Thomsen 2021). Digitalisation of product platforms can also lead to more variable and adaptive products due to the increasing speed of product configuration through digital tools (Sandberg, Holmström, and Lyytinen 2020, p. 140). Here module developers and other stakeholders can also create complementary innovations by generating diverse products, which can decrease the control of platforming firms (Hilbolling et al. 2020, p. 27).

There are several control mechanisms for platforming firms to manage other stakeholders (Thomas, Autio, and Gann 2014, p. 205). Platforming firms can control platform elements such as interfaces (e.g. Baldwin and Woodard 2009; Tee and Gawer 2009, p. 219), modules (e.g. Gawer and Cusumano 2002; Gawer and Henderson 2007), or outputs from platforms (e.g. Tiwana, Konsynski, and Bush 2010, p. 680). For example, control of complementary assets mainly relies on strategically co-specialization of assets, for example, using application programme interfaces of software (West and Dedrick 2000).

When platforms cross into the physical world (i.e. industrialised construction) organising involves shifting constellations of designers, manufacturers, and suppliers, with platform interfaces and digital workflows disciplining information exchange across these distributed stakeholders. To address limitations in the existing platform governance literature, this paper examines how platforming firms govern their stakeholders in open or closed digitally-enabled product platforms. Hence, the study interrogates the nature of governance in hybrid physical-digital settings, the role of process control mechanisms in shaping stakeholder behaviour, and the ways these mechanisms operate under different degrees of interface openness.

Research method

To address our research question we use well-developed case study methods (Eisenhardt 1989; Eisenhardt and Graebner 2007). Our unit of analysis is the firm-level open platforming arrangement such as their process control mechanisms.

Research setting

In this research, we studied firms that own and operate digitally-enabled product platforms. We focus on four firms that use open platforming approaches. These firms use such platforms for delivering industrialised construction for residential, public, and other purposes. These firms studied are operating in economies such as the UK, US and China with interest in using such platforms for industrialised construction.

Case selection

We used a purposive sampling strategy to sample cases, with considerations on the geographical vicinity and accessibility for data collection (Miles and Huberman 1994, pp. 27–28). Sampling boundaries and frame were set in the predefined criteria for case selection – in this research, they are acting as digital systems integrators which operated digitally-enabled product platforms and shared platform interface specifications with external stakeholders. We employed maximum variation sampling to select four construction firms

Table 1. Process control mechanism in managing platforming stakeholders.

Process embedding	Control the stakeholders by embedding processes (including manufacturing, assembly design rules) into the platform (Hilbolling et al. 2020).	Example: A 3D-printing platform forces all designers to use its built-in design-for-manufacturing checker. If the design violates thickness or tolerance rules, the system blocks the upload. This ensures that all contributors follow the platform's standards.
Process generativity	Control the stakeholders by make processes insides platforms generative (Chowdhury, Åkesson, and Thomsen 2021)	Example: A modular furniture platform offers an automatic configurator that generates valid design options based on user inputs. Designers cannot create items outside the generated options, so the platform indirectly controls what gets produced while still appearing flexible.

Table 2. Data collection summary.

Case Code	*Source Category*	*Source Details*
Connector in China	Interviews	2 semi-structured CIO interviews (150 minutes)
	Videos	Firm webinars on smart construction, tech, and cost (240 minutes)
	Documents	Project documents, brochures, annual reports, publications, and slide decks (1,580 pages)
	Websites	Project details, shared industry chain info, and news (6 sources, 10 pages)
Integrator in US	Interviews	Semi-structured and colleague interviews with leadership/interns (100 minutes)
	Websites	Firm blogs and official platform websites (5 sources)
	Videos	Firm videos, interviews, guest lectures, and webinars (143.5 minutes)
	Documents	Slide decks and solution leaflets (14 pages)
Coordinator in US	Interviews	Semi-structured CEO interview (45 minutes)
	Videos	CEO interviews and class recordings (182 minutes)
	Documents	Platform pitch slide deck (21 pages)
	Websites	Firm website (1 source)
Orchestrator in the UK	Interviews	Semi-structured and informal director interviews (105 minutes)
	Seminars	Exhibitions, software launches, and open forums (3 sources)
	Videos	Conference presentations, official platform videos, and webinars (280 minutes)
	Audio	Executive podcasts (4 sources)
	Documents	Published books, slide decks, and journal papers (521 pages)
	Websites	Online articles, media packs, and platform/firm websites (13 sources)

Table 3. Backgrounds of leading construction firms studied.

Case Code	Type of firm (origin, primary business)	Market Segment	Location	Relationship with external stakeholders	Sharing of interface specifications
Connector	Digital systems integrator providing manufacturing systems with own product development	Multi-storey housing, institutional buildings	China	Licencing agreement with individual stakeholders (e.g. suppliers, systems integrators, designers) – *'Supply chain sharing'* (Firm website)	Sharing through licences
Integrator	Digital systems integrator with in-house product development and external manufacturing	Multi-storey school, healthcare, data centre, etc.	US	License contract	Shared externally under licences
Coordinator	Digital systems integrator with in-house product development and external manufacturing	Housing	US	Open marketplace to suppliers, systems integrators, designers	Free sharing in the front end, backend rules digitalised into proprietary formats
Orchestrator	Digital systems integrator providing professional service with in-house product development and, and outsourced manufacturing	Multi-storey housing, schools, hospitals, data centre, etc.	UK, with overseas branches	'Consortium' like supply-chain alliances with stakeholders, e.g. suppliers, systems integrators, designers	Open-source interoperable with others

that varied substantially (e.g. different markets they operated in) in their approach to platform openness and control, allowing us to examine how control mechanisms manifest across diverse organisational contexts. Table 2 gives an overview of the four case study firms that we studied.

Data collection

This study relies on secondary data (e.g. archival material, firm websites, annual reports, official documents, slide decks, book chapters), including different sources: 4427 pages of documents (e.g. published books, slide deck used for webinars), and 675 minutes of recordings of interviews, seminars and webinars; and primary data (e.g. interviews, 957 minutes, and observational and ethnographical material such as firm and factory visits with field notes. Table 3 presents a summary of data.

As our research is interpretative, our data collection and analysis are iterative (Miles, Huberman, and Saldana 2014, p. 250). The first author carried out semi-structured and informal interviews with selected senior managers from these firms. A protocol and a database were used for the case study to ensure research reliability. The interviews used a protocol with starter questions including: 1) How do you design the process to share and reconfigure predefined kit of parts (or product library)? 2) How you share and reconfigure modules across projects and firms? 3) Does your firm open kit of parts by sharing with others? How do you protect intellectual properties when doing so?

Data analysis

In this research, we carried out data analysis by revisiting data set and existing theories iteratively (Eisenhardt and Graebner 2007, p. 30). We identified control mechanisms that four case firms developed as part of their open interface strategies. In the first step, we carried out open coding to discover empirical evidence showing repetitive and similar phenomena (Miles, Huberman, and Saldana 2014: p.80). For example, there were some emerging phenomena, such as '*process embedment into backend intellectual properties*' and '*automating processes*'. Next step, we built logical relationship between these codes, then categorised these codes into second-order themes, while revisiting existing theories (Miles, Huberman, and Saldana 2014, p. 87). As fieldwork progressed, there were more emerging phenomena related to the process control mechanisms and governance of platform-based ecosystems. We then applied sub-codes to label these phenomena (e.g. '*control of process embedment*',

'*control of data exchange reliability*') (Miles, Huberman, and Saldana 2014: p. 85).

We compared and contrasted the process control mechanisms in different open interface strategies across cases. Particularly, we examined how platforming firms used such mechanisms to manage their stakeholders similarly or differently. With a focus on process control mechanisms, we analysed how different open platforming firms developed strategies using process control mechanisms, and how such mechanisms were linked with platform-based governance strategies. To illustrate this, Table A1 in Appendix A presents the key themes that emerged during this iterative coding process, supported by representative quotations from our informants and other data sources.

Case descriptions

Table 2 presents the backgrounds of case firms studied. Below are the descriptions of each case firm.

Connector (China)

Connector operates as a digital systems integrator specialising in industrialised construction manufacturing systems. Their flagship platform, *ConnectorPlatform*, integrates manufacturing and assembly processes into a comprehensive digital ecosystem. The platform employs a 'supply chain sharing' strategy, allowing stakeholders (suppliers and designers) to access the platform through licencing agreements. Connector maintains tight control over its manufacturing system while enabling licenced stakeholders to participate in design and delivery processes through the platform. Their approach emphasises integrated manufacturing control, licenced platform access, and a carefully managed stakeholder ecosystem within the industrialised construction sector.

Integrator (US)

Integrator combines in-house product development with external manufacturing capabilities. Their platform, *IntegratorPlatform*, specialises in automated module configuration and integration. The platform's core strength lies in its sophisticated rule-based design systems that govern how modules fit together. Through automated configuration processes, *IntegratorPlatform* can rapidly generate diverse design options while maintaining consistency and quality control. External stakeholders can access these capabilities through licencing agreements, creating a controlled yet collaborative environment for design innovation. The firm maintains strategic partnerships with external manufacturers while keeping core product development in-house.

Coordinator (US)

Coordinator has developed *CoordinatorTech*, a proprietary platform that integrates digital manufacturing and assembly processes. The platform's distinctive feature is its ability to streamline data exchange across various stakeholders while maintaining process control. By opening the front-end of their platform to licenced external stakeholders, Coordinator enables coordinated interaction while preserving control over critical processes. The firm combines this digital coordination capability with external manufacturing partnerships, creating a balanced approach to stakeholder management and process control.

Orchestrator (UK)

Orchestrator represents a more open approach to platform governance, offering two distinct open-source platforms: *OrchHousingPlatform* and *OrchSchoolPlatform*, each tailored to specific construction segments. As a professional service provider with in-house product development and outsourced manufacturing, Orchestrator has established a unique 'Consortium' model for supply chain alliances, building on a collaborative framework that enables supply chains to work together. This model brings together manufacturers and designers in a more collaborative ecosystem. Operating from its UK headquarters with international branches, Orchestrator demonstrates how open platform governance can work effectively in a global construction context.

Findings: openness and control through digitally-enabled product platform

This section presents the empirical findings from the four case studies and explains how platforming firms governed supply-chain stakeholders through distinct process control mechanisms when opening their digitally-enabled product platforms. Table 4 summarises the common and distinctive mechanisms identified across cases and positions them in relation to each firm's degree of interface openness. The analysis shows that all firms relied on process embedding and process generativity as foundational mechanisms to coordinate stakeholders. However, firms differed markedly in how they deployed process streamlining and process improvement controls. These differences reflected strategic choices about interface openness and authority over platform evolution. The findings are therefore organised in two parts: first, we examine the two common mechanisms used across all cases; second, we analyse how process streamlining and process improvement were deployed differently to manage stakeholder engagement under relatively low versus relatively high interface openness.

Common mechanisms: Process embedding and process generativity

The common mechanisms used by all the case firms are process embedding and process generativity to manage their stakeholders in the value chain. Integrator used process embedding to manage its stakeholders. Its Firm blog noted, '*outside companies working with in-house software solutions sign a contract that states any code committed to that project is owned by the company*'. Similarly, Coordinator maintained the relationship by sharing interfaces with a range of stakeholders. It managed stakeholders

Table 4. Common and distinctive process control mechanisms deployed.

		Interface openness			
		Relatively low			Relatively high
Control mechanism	Description of mechanism	Connector	Integrator	Coordinator	Orchestrator
Process embedding	Control the stakeholders by embedding processes (including manufacturing, assembly design rules) into the platform	Common	Common	Common	Common
Process generativity	Control the stakeholders by make processes insides platforms generative				
Process streamlining	Control the stakeholders by streamlining data exchange between them, so that stakeholders can attach to the platform	Proprietary	Proprietary	Proprietary	Democratised
Process improvement	Control the stakeholders by providing improvement of platforming, so that stakeholders can benefit as they the contribute continuously	Highly controlled	Highly controlled	Backend control (open frontend)	Self-initiating

Explanatory notes: 'Proprietary': firms control stakeholders using proprietary format for data exchange; 'Democratized': firms do not control stakeholders by streamlining data exchange; 'Highly controlled': firms highly control stakeholders by providing improvement of platforming; 'Backend control': firms control stakeholders through embedding processes in the backend of the product platform; 'Self-initiating': firms do not seek to control the stakeholders by providing improvement of platforming.

through embedding processes in the backend. Its CEO noted, '*we'll have that backend to allow people to build a commodity*[1]', '*all my CoordinatorTech clients own their CoordinatorTech [. . .] they own the IP, we're just we're a service*' (CEO Interview) Similarly, Orchestrator treated process embedding into the backend as a way to coordinate and manage its stakeholders when sharing interface specifications. Its Director illustrated, '*general things in contracts, [. . .] they (external module developers and stakeholders) get to own we can't even conceive of what some of the foreground IP would look like without the background stuff*' (Conference presentation). This suggests firms can manage external stakeholders through process embedding.

Process embedding control

We found these platforming firms, in order to manage through platforms, can embed processes from value chains as design rules into the platform. In Connector, despite embedding the patented structural modules into its *ConnectorPlatform*, it embedded the process of manufacturing and assembly as design rules into *ConnectorPlatform*, such as '*prefabrication production line management system, rebar production line management system, concrete production, transportation and scheduling management system*' (Platform document). Integrator developed a similar strategy by embedding the process into the backend of platforms. Its VP (Product and Innovation) described '*process*' and '*software technology*' as '*the rules and constraints that you embedded in your system and managed in the backend*'. There is '*control on the process*' to embed '*deductibility, flexibility, repeatability*' so that the stakeholders can shorten the time to market (VP – Architecture and Engineering).

Coordinator embedded the processes of manufacturing or assembly into the platforms. As mentioned by its CEO in an interview, the production process was critical for the platforming firm, '*we own the ability to do that (platform development) [. . .] we are facilitating this*' (CEO Interview). Coordinator embedded the data from stakeholders into the platform, '*they streamline the link directly to the supply chain*' (CEO Interview). It also embedded DfMA (design for manufacture and assembly) process as design rules, '*DfMA tactics to streamline it, but then build it computationally*' (CEO). Orchestrator, the open-source platform, embedded '*massive heritage*' and '*all of that learning*' from its previous projects into the platform (Director - Conference presentation). As noted in its online article – '*translated their space standards and best practice design rules into a set of spatial design clusters. We then embedded these into (platforms)*', it embedded those space and '*best practice*' processes as design rules into platforms. Because this embedding is present across all four firms, it highlights the process embedding process as a common theme in our case studies.

Collectively, these four cases indicate that platforming firms governed stakeholders under conditions of interface openness by embedding processes into the platform itself. By translating manufacturing requirements, assembly constraints, and production knowledge into digitally-enabled product platforms, firms shaped how external module developers could contribute while retaining control.

Process generativity control

As shown in Table 4, all of those platforming firms (Connector, Integrator, Coordinator, and Orchestrator) adopted process generativity control as a control mechanism. Connector utilised BIM and automatic design rules to derive a diverse range of module configuration in a short time. As noted in a pseudonym, stakeholders can '*use the pre-loaded ConnectorPlatform structural technical rules, fast decomposition plan, automatic decomposition of structural modules and prefabrication ratio*' (Platform document). Integrator also automated the module configuration process, '*not just design modules, but the associated rules and codes that define how those components go together*' (Firm blog). Its *IntegratorPlatform* can generate a wide range of design options in a short time. Its VP illustrated, '*many design options [. . .] before you get into millions and billions of different variations*'. *IntegratorPlatform* supported design iterations – '*test multiple design iterations to ensure the best design is selected*' (Website). Integrator also realised the importance of '*maximum flexibility*' so that stakeholders around platforms can generate products to suit different customer requirements.

Similarly, Coordinator regarded process generativity as the core of its assets. Its CEO mentioned *'automation diversity'*, which can let stakeholders retain module developers and even users of platforms staying within its platforms, then generate a diverse range of future products. In return, users and stakeholders can benefit from the great *'diversity'* the platform offered (CEO interview). Underpinning the generativity was the design automation – *'looking at the process, we're automating the process and the process is where your IP […] your value is'* (CEO), supplemented its CEO. Coordinator used design automation to facilitate the process generativity.

Orchestrator, the open-source platforming firm, made the processes more repeatable so they can generate more options. Its Director noted, *'an algorithm that'll generate you 5000, 50,000 completely compliant things'* (Recorded interview). Another Director demonstrated that *OrchHousingPlatform* can achieve – *'design an apartment building in half an hour'*. The platform enabled users to generate compliant designs more quickly through generative algorithms.

Different mechanisms: Process streamlining and process improvement

Across cases, we found that platforming firms used *process streamlining* or *process improvement* control in various ways to manage their external stakeholders in the value chain. As shown in Figure 2, we synthesise these two mechanisms used differently by four case firms, which may relate to their interface sharing strategies.

Process streamlining control

We found that the non- open-source platforming firms (Connector, Integrator, Coordinator) used process-streamlining control to manage how stakeholders exchanged data and performed design or configuration tasks. Process-streamlining control referred to the way a platform standardised, constrained, and channelled data flows and workflows so that stakeholders had to operate through the platform's prescribed processes. By controlling how data moved between stakeholders, platforming firms enforced compliance while still allowing some interface openness.

Integrator used process streamlining by building its platform on a proprietary design-authoring software owned by one of its investors. Through this arrangement, *IntegratorPlatform* controlled how design information was generated, shared, and updated. As the firm blog described, the system '*worked as a configurator … to constrain the design team, and make sure that they adhere to the rules*'. The platform stored and version-controlled design data, enabling improvements to be '*captured and tracked from design to construction*' (VP, Firm blog). In other words, by tightly regulating the data pathway, Integrator ensured that all design work passed through its platform, which reinforced its ability to govern stakeholder behaviour.

Coordinator applied a similar approach. It '*bridged the data between suppliers and designers*' (CEO), which meant stakeholders had to exchange geometric and technical information through *CoordinatorTech*'s frontend visual-coding interface. Stakeholders could not exchange data freely; they had to use the platform's proprietary format, which removed redundant work and reduced inefficient back-and-forth between module developers. The CEO highlighted this benefit: '*bridging the data … empowering architects to design within the realm of what's achievable*'. By structuring how data flowed, Coordinator reduced friction while strengthening its control over the design and coordination process.

Connector also streamlined data exchange by integrating proprietary workflows and supported formats into *ConnectorPlatform*. Although the platform supported multiple mainstream design and engineering tools, stakeholders who

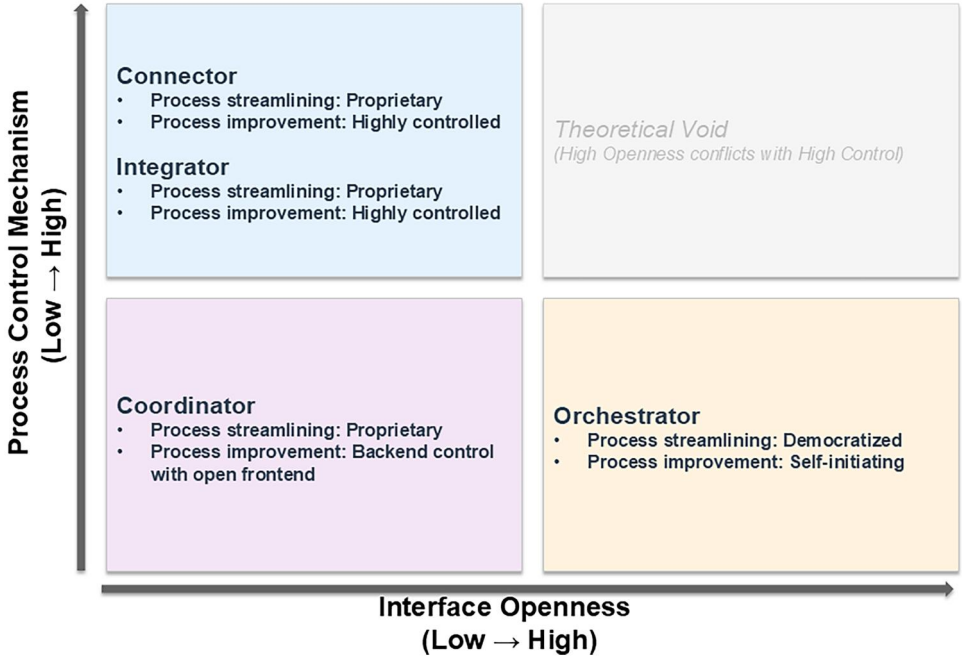

Figure 2. Strategic positioning of four case firms between interface openness and different process control mechanisms.

wished to configure or derive building systems had to route their work through *ConnectorPlatform* to translate design inputs into standardised, manufacturable building systems. In this way, Connector streamlined the end-to-end design-to-manufacturing coordination process, including design configuration, data validation, version control, and handover to production, thereby shaping how stakeholders participated across the supply chain.

In contrast, Orchestrator did not use process streamlining as a control mechanism. Its two open-source platforms promoted a '*democratized design process*' (Conference presentation). Orchestrator made its code openly available – '*the code is on GitHub*' – allowing stakeholders to reconfigure, modify, and optimise designs independently. The Director described this as '*easy to reconfigure your design, modify it, and optimize*'. Because data exchange was not constrained within a proprietary environment, stakeholders could interact more freely and repeatedly return to the platform to refine their systems. Orchestrator therefore relied on openness rather than streamlined control to engage stakeholders.

Overall, process-streamlining control was a mechanism through which Connector, Integrator, and Coordinator managed stakeholders by controlling data pathways and enforcing standardised workflows, while Orchestrator deliberately avoided this mechanism to support an open and decentralised mode of coordination.

Process improvement control

Connector, Integrator, Coordinator, and Orchestrator all used process improvement control, but they applied it in different ways depending on how much authority they kept over the platform's evolution. Connector and Integrator kept tight control over future improvements, Coordinator controlled only the backend while opening the frontend, and Orchestrator relied on '*self-reinforcing*' contributions from external stakeholders.

Connector controlled the improvement of *ConnectorPlatform* throughout its development. When the firm launched version 1.0 in 2017, the platform included only precast production lines and related manufacturing facilities such as concrete mixing stations and pump trucks. From 2018 to 2020, the firm developed a proprietary kit of parts for industrialised construction and codified it into digitally enabled kits, interfaces, and design rules. Although these improvements were developed with a major engineering analysis vendor, Connector controlled the overall process. It developed and maintained all design, manufacturing, and assembly processes. From 2020 onward, Connector embedded these improved processes directly into *ConnectorPlatform*. The platform exported design data for manufacturing and assembly while generating future building systems that met production requirements.

Integrator also used process improvement control by imposing structured workflows on its platform knowledge and content libraries, including parametric design rules, standardised components, and embedded performance logic. These workflows '*allowed us to continue to fine tune and refine [our] processes*' (Firm website) by systematically incorporating lessons from repeated project delivery. The firm designed these workflows to secure consistent feedback from project execution, such as information on design performance, constructability, and downstream manufacturing outcomes, which the firm described as creating an '*improved data flow*' between design and construction. Integrator used this continuous improvement to maintain strong links with external stakeholders. It also regulated stakeholder involvement by formalising how intellectual property was shared within the kit of parts and associated design rules. By doing so, the firm retained control over the platform–supply chain connection.

Integrator also used process improvement control by imposing workflows on its intelligence and content libraries. These workflows 'allowed us to continue to fine tune and refine my processes' (Firm website). The firm designed these workflows to secure consistent data feedback, creating '*improved data flow*' between design and construction. Integrator used this continued improvement to maintain strong links between its firm and external stakeholders. It also regulated stakeholder involvement by formalising how intellectual property was shared in the kit of parts and design rules. By doing so, the firm kept control of the platform–supply-chain connection.

Coordinator controlled improvement by isolating the backend of its platform while keeping the frontend open as a visual-coding environment. Stakeholders could create or trade modules with one another – '*bring everybody together, and actually commoditize your design*' (CEO). This arrangement encouraged stakeholders to remain on the platform and contribute iterative improvements. Because Coordinator controlled the backend code and design automation logic, it directed how these improvements were integrated into the platform.

Orchestrator used a different model based on self-reinforcing improvement. As the owner of two open-source platforms, *OrchHousingPlatform* and *OrchSchoolPlatform*, Orchestrator encouraged stakeholders to contribute improvements on a self-initiating basis. This *self-reinforcing* strategy invited external contributions to platform development while preserving Orchestrator's authority over the platform's core assets. Although code and design rules were openly shared, Orchestrator retained control by owning the copyright and by governing how contributions were reviewed, integrated, and released in subsequent platform updates.

As described by its Director, '*continued improvement and like manufacturing does very well*', Orchestrator treated continued improvement as '*learning feed into the next generation*' of products. It also promoted continued improvement by enabling stakeholders to feed their contributions back into the platform without interference. Its Director explained in a podcast:

> So we've effectively open sourced all of the work we've done for platforms. […] with (one client), we've already said that results of that will get fed back into the Hub […] bring all these things together. And create this sort of self reinforcing

Here, the Hub refers to Orchestrator's centralised platform repository where validated stakeholder contributions, design rules, and project learnings are consolidated and incorporated into subsequent platform releases. Through this arrangement, Orchestrator enabled a virtuous feedback loop

in which external contributions informed platform development, and improved platform capabilities, in turn, encouraged further stakeholder engagement.

Through democratising and self-reinforcing continued improvement, Orchestrator engaged external stakeholders across the supply chain.

> we wanted to embrace and encourage this engagement in the school design process. And that is why we conceived of the OrchSchoolPlatform as being both a design tool and a game. we see future where children can also contribute to the design process (Director in an official video)

In this way, Orchestrator and its stakeholders generated a reinforcing feedback loop—described by the Director as *'a nice kind of reinforcing circularity that public and private sector working together of can scale this up and start to demonstrate enormous benefits'*.—through which both platform owners and contributors continuously enhanced supply-chain capabilities. Orchestrator thus managed stakeholders through a self-reinforcing improvement mechanism that combined open participation with retained ownership of core platform assets.

Across cases, process improvement acted as a control mechanism because platforming firms shaped how platforms evolved and how stakeholders contributed to future capability. Connector and Integrator maintained centralised control over improvement; Coordinator balanced an open frontend with a controlled backend; and Orchestrator enabled decentralised improvement while retaining ownership and governance of core assets.

Summary of findings

In summary, we identified two common process control mechanisms used by all platforming firms, i.e. *process embedding* and *process generativity*. By unpacking different process control mechanisms from platforming firms towards external stakeholders, we identified two mechanisms, i.e. *process streamlining* and *process improvement*, which some firms may use differently and may link to their openness strategies.

Discussion

Our study advances the understanding of platform governance in the context of digitally-enabled product platforms, particularly on how firms balance openness and control in complex supply chain relationships. We structure our discussion around three key theoretical contributions to platform governance and product platform literature.

Our first contribution extends platform governance theory (e.g. Menon, Kärkkäinen, and Wuest 2020; Tiwana, Konsynski, and Bush 2010). While previous research has primarily focused on purely digital platforms (e.g. Gawer and Cusumano 2014) or traditional product platforms (Thomas, Autio, and Gann 2014), our findings illuminate unique governance challenges and solutions in hybrid physical-digital contexts. Process embedding mechanism we identified differs from traditional platform governance in several ways. Unlike pure software platforms where governance primarily concerns API specifications (Tiwana, Konsynski, and Bush 2010), our cases show how firms embed both physical production constraints and digital design rules into their platforms. For example, Connector's embedding of manufacturing processes into digital workflows represents a novel form of governance that bridges digital and physical domains. Specifically, while Hilbolling et al. (2020) emphasise that platforming firms can leverage embedding control to other scalable platforms for complementary innovations, our study highlights that such embedding can also be between platforming firms and module developers.

Our most significant theoretical contribution is the identification of process streamlining and process improvement as novel control mechanisms that platforming firms use to manage external stakeholders. This study enriches the theoretical understanding of platform openness and control strategies within construction supply chains (e.g. Bäckstrand and Fredriksson 2022; Gosling et al. 2015; Gosling and Naim 2009).

While embedding and generativity are the 'common' mechanisms required to establish a physical-digital platform, our findings show that streamlining and improvement are the distinctive, strategic levers firms adjust to manage supply-chain interactions across varying degrees of interface openness. By unpacking these new mechanisms, we provide a clearer explanation of how firms resolve the 'openness paradox' (Cenamor and Frishammar 2021; Jacobides, Cennamo, and Gawer 2018). When interface openness is relatively limited (as seen in Connector, Integrator, and Coordinator), firms deploy proprietary process streamlining to force external stakeholders to route their data through firm-controlled, standardised pathways. Simultaneously, they maintain highly centralised, backend control over process improvement, ensuring that any supply-chain innovations are captured and validated by the platform owner.

Conversely, when a platforming firm pursues a higher degree of interface openness (as seen in Orchestrator), these mechanisms must shift. Rather than relying on proprietary streamlining, the firm shifts to democratised streamlining—allowing open, decentralised data exchange—and relies on self-initiating, self-reinforcing process improvement loops where external stakeholders feed learnings back into the platform's core assets. By newly identifying streamlining and improvement, this study extends platform governance theory by illustrating a menu of adaptable mechanisms that construction firms can configure to retain control over value creation while scaling their open supply-chain ecosystems.

Conclusion

This study advances understanding of platform governance by examining how firms manage supply chain relationships through digitally-enabled product platforms. Through comparative analysis of four leading firms, we identify and theorise key governance mechanisms that enable firms to balance openness and control in platform-based ecosystems. To advance platform governance theory, future scholarship should pivot towards examining dynamic, configurational approaches to these control mechanisms. This theoretical shift is imperative as emerging generative technologies exponentially amplify platform generativity, disrupting

established digital design rules and fundamentally reshaping how platforming firms, i.e. digital system integrators must enforce compliance and capture value in hybrid physical-digital environments. This can also help firm executives and policy makers to navigate their relevant decisions on platform interface strategies and supply-chain relationships.

Process control mechanisms in physical-digital platforms

Our research extends platform governance theory by identifying four distinct process control mechanisms - *embedding, generativity, streamlining,* and *improvement* - that bridge physical and digital domains. Unlike purely digital platforms, these mechanisms must account for both physical production constraints and digital workflows. This contributes to construction platforming literature (Aksenova and Oti-Sarpong 2024; Hall, Whyte, and Lessing 2020; Jones et al. 2022; Zhou 2024), by showing how platforming firms can act as digital systems integrators while maintaining control over co-creating value with external stakeholders in the supply chains.

Governance choices across degrees of interface openness

Our findings indicate that firms can select and align configurations of process control mechanisms with a chosen degree of interface openness. When interface openness is limited, platforming firms tend to configure process control mechanisms in ways that centralise coordination and tightly couple stakeholder contributions to proprietary workflows. In such configurations, process streamlining and process improvement mechanisms are designed to funnel external inputs through firm-controlled systems, ensuring compliance with embedded design rules, production constraints, and performance standards. This alignment allows firms to open selected interfaces for efficiency or scalability purposes while retaining authority over how value is created and captured across the supply chain.

By contrast, when firms pursue higher degrees of interface openness, governance coherence is maintained through a different configuration of process control mechanisms. Rather than relying on proprietary streamlining, firms emphasise process generativity and self-initiated process improvement, enabling external stakeholders to propose modifications, develop complements, or contribute learning back into the platform. Crucially, openness at the interface level does not imply the absence of control; instead, control is re-located to mechanisms governing contribution validation, integration, and platform evolution. Ownership of core assets, design standards, and update authority allows firms to sustain strategic control while accommodating decentralised innovation.

Implications to practice

This study calls for executives' attention to the interface openness for those construction firms crafting their digitally-enabled product platform strategies. As firms start developing digitally-enabled product platforms and managing stakeholders, it is necessary to consider suitable process control mechanisms that platforming firms wish to exert onto stakeholders for preferred relationships, e.g. ongoing, coordinated collaborations with recurring partners, contrasted with one-off transactional relationships. Assessing supply chain relationships through the lens of control versus openness helps firms choose the best mechanisms for coordination and collaboration. For example, 'open' has become a key principle in *Product Plattform Rulebook* (Construction Innovation Hub 2022). This study offers valuable insights to those firms either as platforming firms or module developers for platform governance, in which process control mechanisms are important when they decide to open up. This shift may be challenging and unfamiliar for firms accustomed to traditional contractual relationships in construction, which emphasise fixed scopes and bilateral agreements, as platform-based governance requires ongoing coordination and relational engagement across multiple actors over time.

Implications and new directions for scholarship

The platform openness strategy has become one of the determining factors for platform governance (Cenamor and Frishammar 2021; Gawer 2014; Gawer and Cusumano 2014; Thomas, Autio, and Gann 2014). Platforming firms can choose hybrid open interface strategies for governance as the relationships and interdependences between owners and external stakeholders in the supply chain become increasingly complex (Hilbolling et al. 2020).

As this research focuses on the different control mechanisms used by platforming firms with different openness, future research can explicitly adopt a configurational approach to platform governance, examining how different bundles of governance mechanisms jointly shape platform outcomes. There is an emerging research trajectory on value around platform ecosystems (e.g. Jacobides, Cennamo, and Gawer 2018; Jovanovic, Sjödin, and Parida 2022). While our study treated module developers as a unified group, their positions in the supply chain may significantly influence platform governance dynamics. Future research could examine how different types of module developers (e.g. designers, manufacturers) influence platform evolution and governance needs.

Expanding beyond current frameworks, future scholarship can also explore the disruptive implications of generative technologies (e.g. Generative Artificial Intelligence or GenAI) on the openness-control paradox. Current platforms mostly rely on rule-based design automation to achieve process generativity. GenAI, however, could exponentially scale this generativity by enabling highly autonomous stakeholder co-creation. Researchers must examine how platforming firms will adapt their *process streamlining* and *process improvement* controls to manage AI-generated modules. Key questions include how digital system integrators will protect their embedded backend intelligence, validate AI-generated inputs against physical manufacturing constraints, and ensure that

decentralised, AI-driven contributions feed into a controlled, self-reinforcing platform ecosystem.

Note

1. Authors' explanatory notes: *"Commodity" here means a set of digital models of building modules.*

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Author contributions

CRediT: **Shanjing (Alexander) Zhou**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing; **Daniel Hall**: Supervision, Writing – review & editing; **Jennifer Whyte**: Funding acquisition, Supervision, Writing – review & editing.

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Appendix A

Table A1. Summary of qualitative themes and representative quotations.

	Connector	Integrator	Coordinator	Orchestrator
Descriptions of case firms	A China-based digitally-enabled systems integrator and manufacturing system provider with own product development	A US-based digitally-enabled systems integrator with in-house product development and external manufacturing	A US-based digitally-enabled systems integrator with in-house product development and external manufacturing	A UK-based professional service firm with in-house product development and systems integration, and outsourced manufacturing
Theme	Representative quotations			
Process control mechanisms				
Process embedding	Embed manufacturing and assembly processes into platforms: "Embed with prefabrication production line management system, rebar production line management system, concrete production, transportation and scheduling management system" (Platform document)	Process embedding in the backend: "it's a lot about the process […]. that software technology that supports those processes, the rules and constraints that you embedded in your system and managed in the back end", "IP is that combination of process technology more than just […] the physical thing that comes out the end" (VP, Architecture & Engineering); Design rules and constraints embedding: "pro open approach […] with my development of IntegratorPlatform, […] to embed a lot of those processes and those rules and those constraints that you develop on system into a managed system in the cloud" (VP, Architecture & Engineering); Embed the design and fabrication process: "Companies want your IP in the corporate library, because that's what allows the supply chain to be connected from design to fab" (Firm blog);	Embed supply chain data into platform: "they use computational design to to allow them to be adaptable to fit within the realm of what's achievable, then they streamline the link directly to the supply chain" (CEO Interview); Embed DfMA process: "we established a supply chain, where we actually went out and we don't own those machines. But we found out what the machines are running in their process, help them along the way with the DfMA tactics to streamline it, but then build it computationally" (CEO)	Embed into backend IP: "built on this kind of massive heritage of everything we've done for all the different clients and tested and prototype" (Conference presentation); Embed learning into platforms: "platforms […] take all of that learning all of that benefit from every other client and sort of embed it in a set of components that the industry can more generally benefit from" (Director); Embed programme and cost into platforms: "If you then combine that with the digital tools that allow us to create better coordinated models, data rich designs, where we have programme cost supply chain data embedded in the model"; Embed design rules into platforms: "translated their space standards and best practice design rules into a set of spatial design clusters. We then embedded these into (platforms)" (Online article)
Process generativity	Automation decomposition processes: "use the pre-loaded *ConnectorPlatform* structural technical rules, fast decomposition plan, automatic decomposition of structural modules and prefabrication ratio" (Platform document); BIM-based design automation process: "extract module design model of Software1, Software2 (pseudonym), capture size, strength, bill of material of modules, reorganize process data according to production systems" (Platform document)	Automating design processes: "able to capture not just design modules, but the associated rules and codes that define how those components go together, how they must be fabricated and installed, and what materials are needed to facilitate and automate the process" (Firm blog); "scaling design, manufacture and construction processes, the company delivers unlimited design options, shorter build schedules and improved quality" (Firm website); Automatic deriving building design: "If you design and code parts properly, you should be able to allow for, […] millions or billions of possible design options with a good to the parts, it doesn't take many design options on the sleeve before you get into millions and billions of different variations. So maximum flexibility, designing that for configurability is really important" (Firm guest lecture)	Automating configuration processes: "you're looking at the process, we're automating the process and the process is where your IP […] your value is. So let's digitise that and automate that. […] not looking at it as a one off, or you know looking at it as an one-off standardised component, or having to repeat and create a catalogue of different types of that one, credit one digitally, and you don't need different types of it" (CEO); "then automating a lot of the redundant work that we have to sort of go through and that inefficient process […] streamlined design process. And then we're just sort of sitting there facilitating that data bridge" (CEO); Automating design diversity: "there's more diversity on the platform" (CEO Interview);	Automating processes: "Given that we have fewer processes that are very highly repeatable, you can then start to say, Ill, how can we take that process, and can we apply some level of automation to it" (Podcast); "we'd be assessed on my nine year old who can design in my code compliance school in about 15 minutes" (Recorded interview); Generating a variety of design quickly: "we can get an algorithm that'll generate you 5000, 50,000 completely compliant, you know, things" (Recorded interview); "that is why we conceived of OrchSchoolPlatform being both a design tool and a game. we see future where children can also contribute to the design process" (Official video)

(*continued*)

Table A1. Continued.

	Connector	Integrator	Coordinator	Orchestrator
Process streamlining	Provide data to support manufacturing and production: "provide data to automated production of prefabrication component, provide digital twin of design, manufacturing and construction stages" (Platform document); Bridge design with manufacturing and production processes: "Use (one system) to interoperate […] national and international main-stream component design authoring software, automating extracting data from size, strength, bill of material from Software1, Software2, Software3 to design models, enable manufacturing facilities directly by reorganising data from production systems" (Platform document); Proprietary data control: "Sign with a major software developer in China" (Webinar slide); "core technologies and software, full set of intelligent equipment" (Platform document);	Adhere rules on proprietary software: "if we am able to store that data, and add version control, enhancements can be captured and tracked from design to construction, meaning the enterprise benefits from improved data flow" (Firm blog); "*IntegratorPlatform* works as a […] configurator it's really there to constrain the design team, and make sure that they adhere to the rules", "Data-at-the-centre built on (a major proprietary third-party software)" (Firm guest lecture);	Facilitate and dominate the data exchange from stakeholders: "bridging the data between suppliers and designers, and empowering architects to design within the realm of what's achievable" (CEO), "then automating a lot of the redundant work that we have to sort of go through and that inefficient process […] streamlined design process. And then we're just sort of sitting there facilitating that data bridge" (CEO); Proprietary data format to bridge stakeholders: "when we create although that *CoordinatorTech* is built on a library of components, we're packaging the *CoordinatorTech* in its own right as a as a node. So we see an open source platform where *CoordinatorTech* will be represented in a marketplace on a visual coding platform, so that anybody can start to create their own digital product leveraging a supply chain for us them" (CEO)	Democratise design process via open source: "open sourced and that they democratise the design process of things" (Conference presentation); "*OrchHousingPlatform*, which is the housing design, app, *OrchSchoolPlatform* is the school design app. All of that is open source the code, the code is on GitHub" (Recorded interview)
Process improvement	Manage the improvement along with software updating: "in 2017, Platform 1.0 […] from 2018 to 2020. Platform 2.0 […] from 2020, Platform 3.0" (Platform document),	Manage the continuous feedback and updates: "storing of all that intelligence in a kit-of-parts and content libraries that embodies industrialised construction and allows us to continue to fine tune and refine my processes", "if we are able to store that data, and add version control, enhancements can be captured and tracked from design to construction, meaning the enterprise benefits from improved data flow" (Firm blog);	Continuous feedback from stakeholders: "manufacturer is less likely to have to say, well, you have to use the whole system, […] they're going to have the continuity running through the factory anyway, and bettering their product, […] and specialising more" (CEO Interview); Self-initiating improvement by platforming stakeholders: "everybody will be able to create their own and there'll be an open source back end for everybody to be able to trade and use each other. So you'll be able to use other people's sub components in your product. […] you might just bring everybody together, and actually and commoditize your design" (CEO Interview);	Reinforcing platforming firm value chain: "an open ended process of continuing improvement in my buildings, all of which will feed into the next generation of components" (Podcast); Positive feedback loop from platforming stakeholders: "creating a positive feedback loop that incentivizes still more users and contributors to adopt the platform and join the ecosystem" (Published book); Self-reinforced value chain: "will get fed back into the Hub […] bring all these things together. And create this sort of self-reinforcing", "started from (one public owner) then got picked up more centrally by (one infrastructure authority) that influence what happens in the hub, private sector clients […] picking this up to feed it back in" (Director – Podcast);