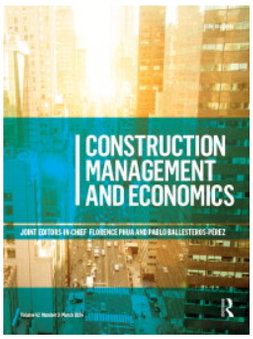

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Beyond "platformania" in the construction sector: Conceptualisations and implications of product platformisation in the UK

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ABSTRACT

The UK government's recent transformation agenda focused on a Platform approach to Design for Manufacture and Assembly (P-DfMA) has attracted interest from the construction sector. A closer examination of the P-DfMA agenda raises questions about its origins and implications. This paper critically analyses grey sector literature, policy and government-supported reports on P-DfMA to discuss how it has been conceptualised, and the implications for the growing "platformania" in the UK construction sector. To this end, firstly platform conceptualisations are synthesised, and distinctions between product platforms and DfMA are highlighted. Secondly, based on an analysis of policy and related documents, five areas critical to driving the platformisation agenda are identified: Product platform development; digitally designed components; platform leadership and ownership; platform governance; and business models. The critical analysis suggests that product platformisation in the UK construction sector requires two distinct types of platform approaches: the product platform; and a transaction platform or a marketplace for buyers and sellers of the components of product platforms. The implications of both for the strategic organising of construction firms, and the five areas identified, are discussed and synthesised with the evidence from management literature. Practical and policy implications for sector stakeholders are outlined, along with questions for future research on product platformisation in the construction sector.

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Introduction

For decades, the UK construction sector has been criticised for continuously struggling with its performance in design and manufacturing, and overall productivity (Latham 1994, Egan 1998, HMG 2018). Several criticisms have been associated with the sector's failures. These include difficulties re-using designed components across assets and projects and harnessing the manufacture and assembly of designed components to deliver projects faster, within budget, on time and more safely (Egan 1998, HMG 2018). Attempts to tackle the sector's shortcomings feature a gradual shift in government-led reforms over the past three decades; from more management-centred approaches promoting collaboration (Egan 1998, Latham 1994), to more digital and manufacturing technology-focused ones often backed by coercive measures (HMG 2013, 2018, IPA 2019). Indeed, the UK government's narratives and messages about visions and strategies for construction sector innovation and transformation now increasingly emphasise digital processes (e.g. Building Information Modelling (BIM) and manufacturing approaches (cf., Sergeeva and WInch 2020, Doganova and Eyquem-Renault 2009, Garud *et al.* 2014).

The government has more recently introduced a "Platform approach to Design for Manufacture and Assembly" (P-DfMA). This move is in line with the yet-to-be successful technocentric efforts the construction sector to adopt technological innovations en-masse. Among policymakers and implementers championing the technocentric agenda, it is unsurprising that P-DfMA is widely seen as a yet another panacea to the UK construction sector's failures (IPA 2019, 2020, CIH 2021a,b). According to the Infrastructure and Projects Authority (IPA 2021), the government envisages that P-DfMA will help integrate design, manufacture and

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construction with platform approaches, allowing commonality of standardised and manufacturable components to be re-deployed across assets (HM Treasury 2017, 2020, HMG 2020, IPA 2019, 2020, 2021). Underpinning these expectations are narratives that tend to exaggerate the potential of P-DfMA to revolutionise infrastructure delivery, drive productivity, and integration. In contrast, there are comparable sector-wide transformation initiatives failing to deliver similar desired changes to date (Bresnen and Marshall 2001, Green 2021, Zomer *et al*. 2021).

Attempts to mainstream manufacturing-led thinking in the UK construction sector is not new (Egan 1998, EPSRC 1999, Bresnen and Marshall 2001, Winch 2003a). Although the government's ambition to make construction increasingly more like manufacturing keeps growing, the achievement of this goal on a large scale has remained elusive for at least three decades (Oti-Sarpong *et al*. 2022, Green 2021). The take up of manufacturing-led approaches in construction is yet to become widespread for varied reasons that are pervasive sector-wide and are reinforced by practices of construction firms (Hall *et al*. 2020, Jones *et al*. 2021). Regardless, policy-makers seem convinced that P-DfMA will help the government deliver about £50bn worth of socio-economic infrastructure, all the while enjoying the benefits of lower capital expenditure, improved schedule predictability and more effective maintenance, leading to improved asset longevity (CIH 2021a, HMG 2020). The untested potentials of P-DfMA, touted as an innovation for catalysing increased productivity and revolutionising infrastructure project delivery. This has unsurprisingly gained attention among players in the construction sector.

Discussions around P-DfMA and platformisation in the UK characterised by enthusiastic claims and ambitious expectations. Critical attention paid to crucial dimensions that might create room for a successful sector-wide implementation or indeed hinder it remain scarce. The government-led push for P-DfMA and the narratives surrounding it echo similar technology-centric transformation attempts that created a "BIM Utopia" (Miettinen and Paavola 2014, p. 85), with BIM presented as a "panacea to the sector's ills" (Dainty *et al*. 2017, p.697). Developments around P-DfMA in the UK reflect a similar wave of enthusiasm and techno-centrism once held about BIM mandates. The excessive enthusiasm for P-DfMA lacks a rigorous counterbalance through critical engagement with relevant literature and theories on platforms. This has created what can be described as "platformania" in the central planks of government policy underpinning construction sector transformation and supported by some key players. Given the importance attached to P-DfMA for "revolutionizing" construction', it is rather surprising that existing narratives are bereft of any constructive critique. This is needed to draw attention to critical implications to inform how any semblance of step changes might be achieved in the sector.

In this paper, we critically analysed documents about P-DfMA in the UK construction sector against mainstream literature on platforms. Our analysis illuminated five critical areas needing greater attention in policy and research to counterbalance the P-DfMA agenda. These are: (1) platform development; (2) digitally designed components; (3) platform leadership and ownership; (4) platform governance, and (5) business model innovation. We argue that these areas need to be thoroughly examined if platformisation may be used effectively to catalyse transformation in the construction sector and realise meaningful outcomes. Building on the above, the paper contributes in two ways. First, we critically review and discuss the current UK agenda on P-DfMA for construction, while illuminating the implications of the platformisation agenda for the construction sector. We argue that the current policy agenda around P-DfMA tends to incorporate a narrow view of product platforms, and their strategic implications for the construction sector are under-emphasised. Second, we present synthesised conceptualisations of platformisation in technology, engineering and innovation management literature to offer clarity on the conceptualisations of product platforms and DfMA. By reflecting on UK platformisation policy and existing platforms literature, we discuss the strategic considerations for and implications of P-DfMA adoption in the construction sector. With platform approaches gaining attention in the sector, these insights give clarity for studies on the subject within the construction management domain and are positioned as complementary to ongoing discussions about policy-backed platformisation initiatives. In the process, we raised the questions for future research.

The paper proceeds as follows. The next section outlines the policy agenda on P-DfMA in the UK construction sector, highlighting government aspirations for value capture from a P-DfMA approach. Next, the platform construct is explained including the differences in technological platforms through a synthesis of relevant management literature. This is followed by distinguishing product platforms from DfMA to aid our analysis and discussion. A description of documents analysed, and a review of the UK product platforms agenda follow, along with a discussion of the five areas identified, which are juxtaposed to insights drawn from management literature. We conclude by highlighting managerial and policy implications,

stating the study's limitations and outlining questions that set the agenda for future research.

Policy agenda on platform approach to design for manufacture and assembly in the UK construction sector

Platform approach to Design for Manufacture and Assembly (P-DfMA), a new term in the UK construction sector, emerged from discussions between Bryden Wood[1] and government representatives (Bryden Wood 2021, Bryden Wood 2017a,b, 2018, Masters and Johnston 2019). The plan for the UK government to implement P-DfMA was proposed in 2019 in the form of a call for evidence for "a new approach to building" (IPA 2019). This announcement was in response to performance targets outlined in the Construction Sector Deal (HMG 2018, CIH 2021a) and followed the self-reported success of Bryden Wood in adopting this approach in 2016 (Bryden Wood 2017a, b, 2018). However, according to Masters and Johnston (2019, p.23), the ideas underpinning P-DfMA "were developed by Bryden Wood … and it is now supported by the UK government as part of its drive towards the greater use of offsite manufacturing in public sector construction projects". This assertion is confirmed in government-backed and other publications that indicate the "seminal" work of this organisation in platforms for the construction sector (see: CIH 2021a, CIH 2022, Mosca *et al.* 2020).

DfMA is defined in policy as a "process by which building products, or components, are designed in a way that enables them to be made on a large-scale using machinery and then put together in one place" (IPA 2019, p.5). According to the Construction Innovation Hub (CIH)[2] P-DfMA, which is an extension of DfMA, is "a term that is widely used but with consistent elements including: a set of low variety core assets (i.e. components, processes, knowledge, people and relationships); a complementary set of peripheral components that exhibit high variety; and a stable interface that acts as a bridge between the stable core and variable peripherals" (CIH 2021b, p.3). Accordingly, P-DfMA is regarded as the most optimal way of utilising both modern digital and manufacturing technologies. Consequently, in step with the government's technology bias, it seen as the way to "revolutionise" the way public sector construction projects are delivered (CIH 2021a,b). Recent policy documents suggest that the government intends to procure public construction projects based on product platforms. For instance, in The Construction Playbook this intention is made clear, with the government's plan to "procure construction projects based on product platforms comprising of standardised and interoperable components and assemblies, the requirements for which will be part of a digital component catalogue" (HMG 2020, p. 20). This position ought to examined critically, as similar recent intentions have been implemented albeit partially, at best (Green 2021).

The government envisions that P-DfMA will lead to an improvement in the construction sector's performance, reducing the lifecycle costs of construction projects and products by 30%, and halving construction project delays and greenhouse gas emissions by 2030 (see HMG 2018, CIH 2021a). Recent policy documents detail the expected benefits from a mandate of P-DfMA (IPA 2021, CIH 2021a,b, HMG 2020). Overall, there is emphasis on platform approaches helping to deliver ∼30% of the government's new build portfolio for social infrastructure (e.g. for housing, education, healthcare and custodial purposes). According to the CIH (2021a), the product platform can be used to meet ∼£50bn of works in the pipeline for a total of five government departments (Education, Health and Social Care, and Transport) and ministries (Justice and Defence) over the next five years. It is envisaged that delivering this volume of projects using product platforms will introduce "manufacturing-led thinking" into construction (CIH 2021b), while generating greater societal outcomes, e.g. stable and inclusive employment (IPA 2021). Policy narratives suggesting that a revolution in infrastructure project delivery will be catalysed by "platformisation" seem endless. Therefore, P-DfMA remains a key objective of the government to leverage public sector procurement to demand for its adoption (IPA 2019, 2021, HMG 2020).

There have been previous unsuccessful attempts to make construction "more like manufacturing" (Bresnen and Marshall 2001, Winch 2003b). Yet, the observed wave of platformania remains underexamined at best. To complement ongoing developments around P-DfMA in the UK specifically, and a growing interest in platform approaches for construction in general, there is a need for clarity. Achieving this clarification requires a closer examination of the combined concepts of platforms. Such scrutiny is necessary for unpacking pertinent conceptual issues and practical considerations around platformisation, with ramifications for policy, construction firms, and research. To offer clarity about platforms, the theoretical underpinnings of platform types are discussed next.

Technological platforms

Across industries, the term "platforms" has been used by practitioners and academics for anything that resembles a technological support infrastructure (Meyer *et al.* 2020). To establish clarity in subsequent arguments made in this paper about platform approaches in the UK construction sector, the definitions and types of technological platforms are clarified in this section. Table 1 summarises the observed differences between technological platforms.

Product platforms belong to an engineering design perspective and are mainly technological platforms (Gawer 2014). Although product platforms tend to be owned by one firm, there are product platforms that can be co-created within alliances, falling into a category of external platforms. Digital platforms, on the other hand, tend to be external platforms (explained in Section 3.1). Product platforms, however, can be delivered through digital and non-digital means (Simpson 2004).

A review of the management literature shows a growing interest in technological platforms across various sectors. In the last two decades, research on the subject has diversified, offering more nuanced views of platform types. Thus, scholars have tried to provide an "integrated framework" (Gawer 2014), or a "unified view" of platforms (Baldwin and Woodard 2009). The unified view suggests that platforms "*perform a function that is essential to a broader technological system, and solve a business problem for many firms and users in the sector*" (Gawer and Cusumano 2013, p.421). Under this view according to Gawer (2014), all platforms share the following features that:

> "*(1) federate and coordinate constitutive agents who can innovate and compete; (2) create value by generating and harnessing economies of scope in supply or/and in demand; and (3) entail a modular technological architecture composed of a core and periphery.*" (Gawer 2014, p.1240).

The core and periphery of platforms are based on the concept of modularity which allows variety, scalability and diversity of components necessary for innovation (Baldwin & Clark 2003). The stable components constitute the core (i.e. the platforrm itself), while the complementary components are replaceable and vary, constituting the periphery (Baldwin & Clark 2000a). For example, the Android operating system is a modular platform, the core owned by Google, while its complementors, the component makers, are providers of the Android apps. The Android apps are the components. The component makers make up the ecosystem around the platform core, the Android, and are a periphery made up of components or in other words, Android's ecosystem.

Technological platforms comprise two predominant types (internal and external), which represent distinct forms of business organisation (Gawer and Cusumano 2013). Distinguishing both is relevant to our critical examination of the UK's P-DfMA agenda.

External technological platforms

External platforms fundamentally serve as technological infrastructure for the value creation processes between multiple actors who would otherwise neither interact nor transact. Such platforms offer a foundation for reusable modular components and technologies (Gawer and Cusumano 2013). McIntyre and Srinivasan (2017) claim that these platforms bring multiple users and complementors together to increase the degree of innovation on complementary products and services by reinforcing direct and indirect network effects.

External platforms can be further categorised as transaction, innovation and hybrid platforms (Gawer 2020). Transaction platforms involve "*two groups of agents interacting via "platforms" where one group's benefit from joining a platform depends on the size of*

Table 1. Distinguishing technological platforms.

	Product platforms	Transaction platforms	Innovation platforms
Internal/External	Internal	External	External
Open/Closed systems	Closed or semi-open	Open or semi-closed	Open
Literature domain	Engineering	Economics	Innovation
Conceptualisation	Technological foundation for innovation	Platform as markets, matchmakers, or intermediaries	Technological foundation for innovation
Scope	Narrow	Narrow	Broad
Control	Strict, semi-open or open	Semi-open	Open for third party innovation
Value creation	Scope in supply	Scope in demand	Scope in demand and supply
Role	Coordination in design and delivery for innovation by complementors	Coordination between supply and demand	Coordination for innovation by complementors
Empirical setting	Automotive, aerospace, PC	Service	ICT
Typical markets	B2C	B2C	B2C and B2B
Examples	Intel, Boeing, Toyota	Uber, AirBnB, eBay	Android, iOS

the other group that joins" (Armstrong 2006, p.668). Uber, Airbnb and Etsy are examples of transaction platforms. Such platforms are also called a "marketplace" (Hagiu & Wright 2015). Innovation platforms enable innovation among loosely coupled complementors. This is achieved by providing the technological infrastructure for such growth (Gawer 2014). Innovation is enabled through complementors' differentiation of components around a stable core through modularity, enabling the provision of additional products and services (Jacobides *et al.* 2018). The core is owned and developed by a platform owner (Gawer and Cusumano 2013). Apple, Google and Facebook are examples of innovation platforms. Hybrid platforms, for example Amazon, possess the functions of innovation and transaction platforms (Gawer 2020).

Regardless of category, a platform owner/leader (also referred to as hub, matchmaker, or intermediary) is of strategic importance to the growth of the platform's ecosystem (Iansiti and Levien 2004). Their role is typically to develop a platform as an enabling infrastructure for complementary innovation and govern innovation by the complementors without strict hierarchy and control (Nambisan and Sawhney 2011).

Internal technological platforms

Internal platforms are a set of assets that allow a firm to develop and produce a stream of derivative products (Meyer and Lehnerd 1997). Drawing on Robertson and Ulrich (1998) views, Gawer (2014, p.419) describe internal platforms as "*the assets (components, processes, knowledge, people, or relationships) shared by a set of products*". Such platforms offer a reusable foundation for product development. Underpinning this feature are three principles of product platforms, namely: the modular architecture; interfaces that define how modules interact; and the standards that define the design rules (Baldwin and Clark 2003). They typically exist in manufacturing, aerospace, automotive, and aircraft and can be company or product specific (Gawer 2014, Hilbolling *et al.* 2021, Simpson 2004).

A key feature of internal platforms is the generation of product families. This feature is dependent on design hierarchy and system architecture to guide the development of components and their families (Baldwin and Clark 2000a, Ulrich 1995, Ethiraj and Levinthal 2004). These families of components can be modified, removed, and updated (Gawer 2014). Furthermore, these product families are reusable and scalable across products and assets to potentially achieve economies of scale (Baldwin and Clark 2000a). Thus, the costs of joint production are reportedly more efficient compared to individual component production (Panzar and Willig 1975, 1981, Teece 1980, 1982, 2018). This fundamental feature also arguably enables platform owners to increase product variety to accommodate clients' changing needs, thus achieving economy of scope (Wheelwright and Clark 1992).

Internal platforms are typically owned by firms that take a closed-system approach (Nambisan and Sawhney 2011). This means that a platform owner is a key decision maker in coordinating the interfaces and providing an underlying architecture to ensure that the final product is delivered to the market. Typically, the owner leads the marketing and development of the core innovation and controls strictly the complementary activities performed by its complementors in delivering the components. Product platform owners can also take a different approach. For example, Boeing shifted its thinking towards "design and build to performance" in developing the Dreamliner 787 (Nambisan and Sawhney 2011, p.41). Despite suffering significant delays and budget overruns owing to a mismatch between supply chain capabilities and Boeing's strategy, the supply chain partners were treated differently from the traditional supply chain in terms of autonomy in component design (Shenhar *et al.* 2016). Boeing remained a key decision maker in coordinating the interfaces and underlying architecture to ensure that the final product was delivered to the market. According to Nambisan and Sawhney (2011), firms such as Boeing, Sony, and Rolls-Royce build their products on internal platforms, with full or semi- control over their components, despite the complexity of such arrangements and the challenges they present (Tang *et al.* 2019, Lamba and Elahi 2012, Altfeld 2016, Shenhar *et al.* 2016). The platforms described above are summarised in Table 1.

The review of literature above clarifies what platforms are and the common types that exist. Each type of platform described above possesses distinct characteristics that hold implications for product development and innovation, leadership, supply chain engagement and business organisation. For instance, a critical distinction between internal and external platforms is the degree of openness, which entails aspects of the governance mechanisms set by the platform owner (Gawer 2014). Platform leadership in external platforms often offers a greater degree of autonomy for innovation by complementors than that of internal platforms (Hagiu and Wright 2015, Nambisan and

Sawhney 2011, Rietveld *et al.* 2020). Internal platform owners tend to take a closed approach and design internal systems depending on their business operations. Firms operating in small markets with high costs, low volumes and an oligopolistic software vendors market often choose highly integrated and closed system architectures with proprietary standards favouring internal platforms (Johannesson *et al.* 2017, Simpson 2004). Despite the importance of platform leadership, their roles and the governance mechanisms are underexplored in the existing literature (Jacobides *et al.* 2018, Lichtenthaler 2013).

Next, we distinguish product platforms from DfMA to support our analysis.

Distinguishing product platforms from DfMA

To critically examine the UK's government-backed P-DfMA agenda, distinguishing conceptualisations, approaches, principles and the applications of product platforms from DfMA is essential. This delineation is useful for informing policy and practice, given the growing attention to product platform developments in the construction sector. Indeed, with growing demand for customisation to address client requirements, product platforms have become important to manufacturing business (Johannesson *et al.* 2017). Like product platforms, DfMA is a concept that has been known in the manufacturing sector for a considerable time (Lu *et al.* 2021). Both are design principles requiring distinct forms of organisation. Although DfMA and product platforms are used interchangeably in the construction sector, the constructs differ – albeit with some overlaps.

Product platforms are characterised by modularity, standardisation, scalability (Baldwin and Clark 2000a), and mass customisation (Jiao *et al.* 2007). They run on libraries comprising a collection of component families that can be manufactured and assembled (Simpson 2004). Product platforms facilitate the development of derivative products that can be tailored to changing customer needs (Ulrich and Eppinger 2016). In contrast, DfMA operates on an integral structure which is opposed to modularity and standardisation (Boothroyd *et al.* 2010, Simpson 2004). A key feature of DfMA is that the number and complexity of components are minimised, and design is simplified (Boothroyd 1994, Boothroyd *et al.* 2010). DfMA requires quality design of the product for productivity and performance in manufacturing and assembly (Boothroyd *et al.* 2010). The quality of design has a direct correlation with the product quality and productivity achieved by efficiency in manufacturing and assembly (Boothroyd 1994). Thus, product platforms and DfMA can be seen as being at opposite sides of product organisation, modularity and integration (Ulrich and Eppinger 2016).

Unlike DfMA, product platforms allow innovation in components by complementors, creating space for certain risks in the quality of complementors' designs. The families of components produced by complementors are typically coordinated by a leading hub (e.g. integrator) via standardised interfaces (Meyer and Lehnerd 1997). Modularity and standardised interfaces offer an economy of scale and scope by sharing not only the components across assets, but also the production processes and innovation by the complementors. This approach of product platforms allows firms to stay flexible in responding to changing market demands (Robertson and Ulrich 1998).

Despite the distinctions, products are rarely strictly modular or integral (Ulrich and Eppinger 2016). Product platforms can be either modular or integral; the automotive industry's adoption of integral architecture of product platforms is an example (Muffatto & Roveda 2000). Furthermore, while some studies indicate that some firms are product platform owners, others report that they utilise DfMA. For instance, according to Simpson (2004), Boeing used product platforms to "stretch" its aircraft, while Colin *et al.* (2018) argued that Boeing used DfMA in their design. Despite this seeming contrast, the literature is clear on the role of Boeing as an innovation integrator that coordinates production to enable innovation by its suppliers/co-specialised complementors, underscoring the firm's role as a product platform owner (Nambisan & Sawhney 2011). Table 2 summarises the distinctions between product platforms and P-DfMA.

Adopting product platforms and/or DfMA holds implications for the business strategy and organisation of firms. Therefore, the choice should be carefully considered by firms before implementation (Caffrey *et al.* 2002, Gawer 2014). For example, product platforms have become important for product development in the automotive sector (Magnus and Christer 2005), and the personal computer (PC) industry (Baldwin & Clark 2000a, Gawer 2014). On the other hand, DfMA is prevalent in aerospace; a sector with a small market niche that has historically resisted opening its boundaries. Firms therefore adopt DfMA to control quality of components, intellectual property (IP) and security, and consequently rarely enjoy benefits from economies of scale and scope (Caffrey *et al.* 2002). Overall, firms seeking quality, efficiency and productivity

Table 2. Distinguishing product platforms from DfMA.

	Product platforms (Johannesson *et al.* 2017, Simpson 2004)	DfMA (Boothroyd 1994, Boothroyd *et al.* 2010)
System architecture (Ulrich 1995)	Modular	Integral
Support for Manufacture and Assembly	Manufacturing and assembly	Manufacturing and assembly
Underlying infrastructure	Sharing families of components across a variety of products	Bespoke design of a single product
Production architecture	Mass customisation	Bespoke customisation
Network	Loosely coupled systems	Vertical integration
Phenomenon	Supply chain	Supply chain
Integration approach	Interface standardisation for supply chain innovation, and for scope and scale growth in components	Integration "simplified" and components reduced in number within organisation or supply chain
Product type	Scalable	Bespoke
Approach	Openness, Semi-openness, closeness	Closeness
Market	Can grow market	Small market niche
Approach to Manufacture and Assembly	Coordination	Top-down control
Benefits	Innovation, economy of scale and scope, flexibility, responsiveness, customisation, efficient production, reduced costs	Quality of product, efficient manufacture and assembly, reduced costs of production
Industries	Automotive, Personal Computers (PCs)	Aerospace
Examples	Nissan, Toyota, Intel	Boeing, NASA

would tend to adopt DfMA, while those that aim for scalability, innovation and variety would opt for product platforms.

From the review, three observations can be made. First, product platforms and DfMA are two different streams of literature with little cross-fertilisation. DfMA and product platforms are used in distinct sectors for specific strategic reasons despite being not mutually exclusive. However, firms that use both concurrently for product design tend to utilise product platform families for the majority of components, and DfMA only for specific components (Robertson & Ulrich 1998). Second, the literature suggests that DfMA requires formalisation to support product family design and platform-based product development (Simpson 2004, Yigit *et al.* 2002). Third, from the literature, there is barely any evidence for either the combined concept or the application of a Platform approach to Design for Manufacture and Assembly (P-DfMA) beyond the construction industry in the UK. There is also no clear explanation of the formalisation processes to support the use of DfMA with platform-based product development, either in the management or engineering literature. Meanwhile, the IPA (2020, p.2, 2019, p.6) defines PDfMA as "a set of digitally designed components across multiple types of built asset". This view offers neither any link to DfMA, nor a clear indication on what is core and periphery – nonetheless, it is echoed across other UK policies promoting the idea of P-DfMA (CIH 2021, 2022).

The latter two observations are particularly vital insights to carry forward in examining the UK's P-DfMA agenda. Reflecting on the preceding review exposes how the idea of P-DfMA is a UK construction sector phenomenon that is not grounded in literature per se. The merged concept is rather largely a product of discussions between a sector player and government-backed entities (cf. Bryden Wood 2017a, b, 2021, CIH 2021a, b). P-DfMA, as adopted in UK policy, indicates that firms in the construction sector will need to embrace both product platform and DfMA design principles. It therefore plausible to argue that the CIH is seeking to establish DfMA to support product family design by pursuing P-DfMA (cf. CIH 2021a, b). While P-DfMA encapsulates a combination of product platforms and DfMA, both are two distinct approaches and design principles. They each require a consideration of strategic implications for firms' organisation and competition, as well as on the sector's context beyond system architecture development. The P-DfMA agenda in the UK construction sector therefore warrants closer examination vis-à-vis existing theories and empirical evidence.

Examining the P-DfMA agenda for the UK construction sector

Documents reviewed

The insights presented in this paper are based on an inductive qualitative approach using a thematic document analysis, supplemented with informal discussions with two P-DfMA experts.

Data collection

Our exploratory study draws on data from 20 documents. These comprise a UK government playbook (1) and strategies for the construction sector (4), innovation and transformation roadmaps and reports (4), innovation proposals (2), platform programme (rule)

books (4) and reports (4), and a research report (1). Appendix 1 in Supplementary material provides details of the documents reviewed. These relevant documents are related to the introduction of "advanced manufacturing" or platformisation and a need for new construction approaches. The inclusion criteria comprised a document's focus on "advanced" forms of manufacturing and productization, and the development and/or implementation of a platform approach in the UK construction sector. The documents gathered provided an introduction of P-DfMA – which is a new proposed approach for construction in the UK. They could be treated as sources of relevant data because they are written by key actors that shaped the P-DfMA agenda in the UK (see Appendix 1 and 2, in supplementary material).

Thematic analysis

We followed an inductive approach in thematically analysing the documents collected. An inductive approach was deemed most suitable for exploring the subject of P-DfMA, which is a new concept in the UK construction sector (cf. Clarke *et al.* 2015, Braun & Clarke 2013). Exploring this "new terrain" in the UK construction sector with an inductive approach, allowed us to identify and categorise the emergent patterns from textual data (Saldana 2016, Clarke & Braun 2015, Guest *et al.* 2012). Initial analysis comprised first reading the documents gathered and answering the following questions: (1) what goals are underpinning the platform programme? (2) what are the key areas of focus under the programme? and (3) what critical questions arise for the future of platformisation? This provided an overview of the UK government's agenda and the status of the idea of platformisation for the construction sector. While examining the documents, relevant quotes were extracted, attendant with remarks and observations.

The second stage involved grouping the quotes into themes and developing the overarching dimensions. To this end, firstly, the individually identified relevant quotes were grouped into themes. Secondly, the authors held joint discussions to align the analysis and thematic groupings. Through iterative process, the themes were developed. The third step involved authors separately merging the themes into dimensions and repeating the cycle of discussions for alignment between authors. Where misalignments were identified, the data would be re-examined while consulting relevant management literature. The preceding steps led to refinements from which the five dimensions emerged and are discussed in this paper (see Table 3). Following these steps allowed us to identify the dimensions that capture the critical considerations of the UK's P-DfMA agenda in the construction sector (cf. Saldana 2016). A systematic and inductive approach allowed us to identify the themes and dimensions in a less biased way (Braun & Clarke 2006, Clarke *et al.* 2015, Clarke & Braun 2014).

To ensure consistency, authors repeated the two stages of the analysis so that the various emerging themes and their categorisations accurately reflected the data (cf. Braun & Clarke 2006, Fereday and Muir-Cochrane 2006). Additionally, to ensure trustworthiness of the findings subsequently presented from this analysis, the authors made prolonged, persistent observations of developments in the UK construction sector, cross-checked extracts from the data, and held meetings to discuss the emergent findings (cf. Guest *et al.* 2012, Braun & Clarke 2006, Lincoln and Guba 1985). To complement our analysis, we conducted two-hour informal discussions with two leading UK-based experts in P-DfMA who have been involved in the development of the platform approach for the UK construction sector. These discussions were essential in verifying our analysis and generating critical reflections.

The five critical considerations of P-DfMA agenda in policy documents that are: (1) platform development; (2) digitally designed components; (3) platform leadership and ownership; (4) platform governance; and (5) business model innovation. These areas are presented in Table 3 and discussed subsequently.

Examining the multiple documents helped us construct – from different perspectives – a detailed understanding of developments underpinning the P-DfMA agenda in the UK construction sector. From the analysis conducted, the data extracted are discussed based on the underpinning dimensions of product platforms as identified from mainstream literature. From the example of the UK, the findings presented below contribute to the fledgling literature on platformisation in the construction sector.

Findings and discussion

Product platform development

The documents analysed reveal two critical considerations for UK product platform development. These two considerations are about strategic choices, and platform planning and design.

Table 3. Critical considerations of P-DfMA in policy documents.

Extracts from policy documents	Emerging themes	Aggregated dimensions
• The use of platforms is a strategic choice to design once and use that design across multiple products. It is predominantly a financial strategy.	Strategizing choices for product platforms	Product platform development
• The design, procurement, and construction of built assets use a defined set of standardised and interoperable components (IPA 2019, p.6).	Defining a set of standardised and interoperable components	
• Adapting proven manufacturing processes from other sectors for construction, to develop new rules and standards to improve the safety, assurance and interoperability of platform construction systems (CIH 2021a, b).	Adapting proven manufacturing processes	
• To extend this principle – applying a set of digitally designed common elements (components, rules and processes) across multiple types of built asset, minimising the need for bespoke (CIH 2021a, p.13).	Applying product platform approach to designing common components	
• The Rulebook will ensure data is consistent across product platforms, allowing interoperability and therefore broader potential for application (CIH 2021b, p.8).	Developing a rulebook for data consistency and interoperability	
• Greater use of platforms will require government to harmonise its technical standards (IPA 2021, p.25).	Harmonising technical standards	
• Digital component catalogue will provide the requirements for the suppliers (HMG 2020, p.20).		
• A set of digitally designed components across multiple types of built asset and apply those components wherever possible, thereby minimising the need to design bespoke components for different types of asset (IPA 2019, p.6).	Designing components digitally	Digitally designed components
• Platform-based approaches are an example of how we can use digital and offsite manufacturing technologies to drive the transformation of the construction industry in the UK, improving its performance and delivering better outcomes for clients. (Lee Rowley MP, Minister for Business and Industry)		
• A set of digitally designed components across multiple types of built asset (IPA 2019, p.6).	Utilizing BIM to design components	
• Primed by the government-led Building Information Modelling (BIM) mandate, parts of the construction sector are already using advanced technologies, paving the way for our proposed approach. (IPA 2019, p.4)		
• P-DfMA seeks to [apply] a set of digitally designed common elements (components, rules and processes) across multiple types of built asset, minimising the need for bespoke (CIH 2021a, p.13)		
• The output reflected the need for further definition of the Rulebook, but several common themes emerged, principally that the Rulebook should focus more on: A centralised BIM library of components (CIH 2021b, p.7)	BIM library of components	
• By engaging prospective clients and other members of the supply chain, with select information these product platforms can be construed as semiopen; a tact growing in prominence and regularly, facilitated by the rapid evolution of digital tools such as BIM object libraries. (CIH 2022, p.13)		
• Design information systems: digital/BIM library workflows embed standardized performance requirements into a reduced set of spatial blocks that work with platform systems (CIH 2022, p.53)		
• Government will facilitate the creation of a digital environment to support P-DfMA approaches. […] including the UK BIM Framework, to enable the effective digital management of government requirements. (IPA 2020, p.24)	Supporting digitalization of processes by government	
• [The catalogue], it would be more appropriate to be overseen by an independent body or for the market to decide (IPA 2021, p.15).	Leading a catalogue by an intermediary	Leadership and ownership
• … there is scope for rationalisation and simplification in any process, which would lead to efficiencies … an executive body or custodian commissioning body should be responsible for this (IPA 2020, p.15).		
• The government, in some form, should have this function [component ownership] (IPA 2020).	Creating demand by the government	
• The government has created the right conditions to … accelerate the market for platform construction systems through the new policies set out in the Construction Playbook (CIH 2021a, p.7).		

(*continued*)

Table 3. Continued.

Extracts from policy documents	Emerging themes	Aggregated dimensions
• Leveraging the government's collective buying power to aggregate demand for platforms (IPA 2020, p.3). • Procuring construction projects based on product platforms comprising of standardised and interoperable components and assemblies (HMG 2020).		
• … suppliers will struggle to deliver standardised products with no opportunity to differentiate and add value … a clear boundary between core IP and proprietary IP must exist, to incentivise R&D and design innovation without compromising the openness of the platform (IPA 2020, p.16).	Designing platform openness by setting IPs	Platform governance
• Governance arrangements will be put in place to establish a framework for accountability … to support accelerated adoption of product platforms in construction. It is expected that key principles of Open, Collaborative and Continuously Improving will be upheld (CIH 2022, p.49)	Platform governance principles	
• We anticipate that three key roles will be required for the governance of the Rulebook: Owners (setting the direction, strategy and rules of engagement); Custodians (impartial and independent, ensuring that response mechanisms are established, feedback is gathered, analysed and implementation is mapped into future Rulebook versions); Users (to test application and feedback – including clients, product platform providers, design teams, manufacturers/suppliers) (CIH 2022, p.49)	Roles of actors for platform governance	
• … current contracting models will not be effective in facilitating a P-DfMA approach, and that new models of contracting are required (IPA 2020, p.14).	Seeking new contractual and procurement models for innovation in projects	Business model innovation
• This is a transformation that will require changes in the business models, current skill sets, and the culture of the UK construction industry (IPA 2020, p.22).	Recognising a need to change business models, culture and skills	
• The underpinning of an effective platform is a clearly defined strategy and value proposition, which holds the potential to support multiple market segments as well as to meet multiple customer requirements (CIH 2021a, p.15).	Strategizing for new market emergence	
• … to drive a new market for manufacturing in construction, … provide a stable pipeline of demand to give industry the confidence to invest in new products and manufacturing technologies (CIH 2021a, p.3).		

Strategic choices

The CIH, as the government-backed entity leading the platform programme, recognises that the use of product platforms is a strategic choice for owners of product platforms. There are predominant concerns with the "financial strategy" that determines market choice set by a firm's capabilities and product choice, how to achieve low-cost variety in this market, and separately planning and designing product platforms.

> The use of platforms is a strategic choice to design once and use that design across multiple products. It is predominantly a financial strategy and is only one way to offer variety to customers and projects while reducing the cost-base; it is not universally applicable (CIH 2022, p.25).

Indeed, prior to the development of product platforms, firms must strategize their market segment entry and investment opportunities (Robertson and Ulrich 1998). However, investment can be a significant obstacle for most construction firms as has been the case in past decades, particularly for small and medium enterprises who constitute over 90% of the sector's productive capacity (Dainty *et al.* 2017, Barrett and Sexton 2006). Beyond a financial strategy, another critical dimension for firms is determining their market segment entry strategy, for which Katerra serves as a useful cautionary tale. This involves achieving a product-market fit, which is required before any considerable investments can be made into making a firm "platform ready" and subsequently achieve scalability (Curtis *et al.* 2020).

The UK government's intention to meet a pipeline of public sector projects estimated to be ∼£50bn by looking "to procure construction projects based on product platforms" sets out a market need for platforms (HMG 2020, p.20). The usefulness of this promise to construction sector players in making strategic financial and market entry investment considerations is likely to be scant, considering how the government has failed in various ways in implementing similar "transformation" policies in the past (Green 2021, 2011).

A financial strategy and market segmentation are not the only strategic considerations to be made in

relation to product platforms and their development. Product platform owners are also faced with the following considerations:

- Leveraging product platforms across markets that follows the choice of segmentation strategy as proposed by Meyer (1997).
- Taking a top-down (proactive) or bottom-up (reactive) approach and choosing an integral or modular product platform design (Baldwin & Clark 2000b).
- Exercising dynamic capabilities to sense and seize new opportunities (Helfat & Raubitschek 2018, Teece 2017).
- Leading and governing the platform leadership – which is critical to sustaining the competitive advantage (Gawer & Cusumano 2002).
- Designing business models (Teece 2010).

These additional considerations are crucial for platform development and success (Zhao *et al.* 2019). Despite their importance, the leadership to implement them is often scarce. Most strategic leaders do not have all the required resources and capabilities to initiate, design and deliver new systems (e.g. product platforms). To do so, they often need to cooperate with complementors and competitors (Gawer & Cusumano 2002, Ritala 2012, Horn 2005).

Product platform planning and design

The second consideration is about product platform planning and designing repeatable components. Planning and designing activities are strategic in nature. Yet, from the documents analysed, the focus tends to be largely on the design principles of product platforms, neglecting the enterprise aspect. Our analysis revealed two types of platforms that are implicitly assumed, namely the product platform and "catalogue" – referred to as "library" or a "a kit-of-parts" by the CIH (2021a). The catalogue is described as a marketplace for components supply, owners of product platforms (supply chain firms and manufacturers), and those from the demand side (the system integrators acting on behalf of the public clients) (CIH 2021a,b, 2022). This conceptualisation contrasts with the well-established management literature on design and development of marketplaces, where the marketplace is a type of external platform and typically a transaction platform (Gawer 2020, McIntyre & Srinivasan 2017). The "catalogue" described by the CIH for the UK P-DfMA agenda, would then require a platform owner to establish a matchmaking mechanism between supply and demand and coordinate the value exchange between the two sides. Given the multi-player nature of construction how this would be achieved needs attention.

From the analysis there is an expectation for product platforms to be planned and designed by firms in the construction supply chain and manufacturers. The CIH (2021a) further expects product platforms to include a "configured core" and "periphery" of complementary components. An exact description of the "core" and "periphery" referenced in the analysed documents remains unclear. This lack of clarity raises a question about the development of the platform. Will the core be developed for projects and relate to product design, or in the catalogue itself as an underlying platform? An informal discussion with one P-DfMA expert revealed that the core relates to the structure of a building product, while components around the core are produced by component makers. It means that the core is delivered with DfMA and is bespoke while components, the product platforms, can be scaled. Any attempt at successfully developing and implementing product platforms in the UK construction sector would require clarity about the core and periphery. It will also determine the type of platform, whether external or internal, which would consequently pose strategic platform development and business development questions for future product platform owners. These are imperative.

Digitally designed components

Our analysis highlights an explicit emphasis on the use of BIM for digital component design in the UK's P-DfMA agenda (see Table 3). Although BIM has no universal definition, it can be seen as a set of processes and digital technologies that underpin the design and delivery of projects (Eastman *et al.* 2011). However, in UK government policies, BIM is presented as a shared digital environment or tool necessary for the implementation of product platforms (CIH 2021, HMG 2020). It is therefore seen as a specific technology, instead of a process of designing the building components following a data-driven approach, which is a reductionist and a single technology focused view of BIM.

Sector-wide take up of BIM in the UK remains unattained (NBS 2020). However, the IPA (2019, p.4), espouses that the UK construction sector has been "primed by the government-led BIM mandate" and that "parts of the sector are already using advanced technologies, paving the way for our proposed approach" (i.e. P-DfMA). From the policy documents reviewed, there is an expectation that the government

mandate for BIM in public projects in the UK would provide a foundation and the needed "momentum" for BIM to be used in component design (IPA 2019, p.4). This is an unrealistic view of the utilisation of BIM in practice and how that could be leveraged for the several reasons. Firstly, based on self-reported surveys completed by construction firms the NBS (2020) estimates a 73% take-up of BIM among firms reached, and 27% being (un)aware of and not using it. Worth noting here is that these figures often reflect opinions, rather than actual evaluation of BIM adoption activities; therefore, it is plausible that the former could be less, and latter significantly more in practice (cf. Dainty *et al.* 2017). Secondly, among the construction firms who are reportedly aware of and are using BIM, most have a limited use of it (NBS 2020). The BIM technologies are mostly used for visualisation of products and most treat building information models as mandatory deliverables while using data-driven design principles with non-mainstream BIM technologies (NBS 2019, 2020, Zomer *et al.* 2021). Discussions with leading P-DfMA experts further illuminated that current mainstream BIM technologies have limited capabilities for product platform families and component scalability. They are not suitable for supporting P-DfMA. Thirdly, the reliance on BIM as the vehicle for creating digital components is unrealistic because nearly 60% of firms do not see BIM use as the "new normal" for delivering construction projects. Finally, and possibly most importantly, almost 65% of firms report a lack of client demand as the chief barrier to adopting and using BIM (NBS 2020). This raises concerns about the capabilities of government ministries to demand for the use of platforms from their suppliers in delivering their projects. It is worth noting here that owing to the chronic bias of self-reporting, the indicative statistics presented by the NBS could be far worse.

From our analysis, the CIH indicates that the digitally designed component catalogue under the platform programme must be open or semi-open (CIH 2021a, b). This means that the digitally designed components should not be locked in with a specific BIM software. It is therefore crucial for the catalogue to hold components that are shareable via open standards (i.e. the Industry Foundation Classes (IFC)) for visualisation purposes while their suppliers preserve their intellectual property (IP). IFC is an open BIM standard for file exchange and visualisation (Laakso and Kiviniemi 2012, BuildingSMART, n.d.). Its use in the UK is yet to see sector-wide take-up, as almost 70% of firms in the sector are reported to prefer simply following a naming convention for sharing digital building information (NBS 2020). Digitally designed components can consequently be locked-in by software providers, leaving little opportunity to realise the planned open and semi-open approach necessary for scalability and open competition. It is worth noting that the development of digital interoperability between BIM technologies and open standardisation in the construction sector has been ongoing since the 1990s (Laakso and Kiviniemi 2012). Although the sector has seen some progress, initiated by BuildingSMART, with certifications for software with open standards and interoperability, full interoperability across systems remains hard to accomplish (CIH 2020). Indeed, interoperability between software is a strategic issue related to the power dynamics in the software market that can be observed across industries (David and Greenstein 1990, Aksenova *et al.* 2019). These are significant challenges to be confronted for the product platform agenda to catalyse any transformation in the sector. To support the product platform agenda, technology lock-ins should be addressed by the sector and the government. If digitally designed components are supported with open standards and competition on the software market, they can be added in catalogues or a marketplace for visualisation purposes for clients. Although interoperability is not a pre-requisite for a catalogue as its purpose is to mediate the supply of components with demand, standardisation of interfaces for product platforms is useful. Addressing the challenges of standardised interfaces and shareability makes clarity around component ownership crucial.

Platform leadership and ownership

Our analysis revealed three main issues about leadership and ownership. Fundamentally, platforms require strategic leadership to determine how the platform is operated and governed (Gawer & Cusumano 2002, Iansiti & Levien 2004). This involves setting rules, establishing roles and determining governance mechanisms to ensure the success of a platform (Gulati *et al.* 2012). Performing any of these governance processes is determined by the type of the platform; owners of transaction platforms would strategise and govern their platforms differently from product platform owners. This is fundamental because of platform architecture and ecosystem organisation.

From our analysis, emphasis in the platform agenda is primarily on the government's role as a client in creating demand for the use of platforms. Despite this focus aligning with the procurement intentions set

out in the Construction Playbook (see Table 3), there is a degree of vagueness regarding the specific role the government may play beyond creating a demand for the product platforms. Furthermore, we identified that the need for role specificity is imperative for at least three distinct leading actors under the CIH-led platforms programme. Clarity about who should be playing the following roles is crucial: (1) ownership of product platforms and their families; (2) the intermediaries that own and govern the catalogue and mediate supply with demand, and (3) public organisations that should lead and develop requirements for the procurement of components via catalogues and represent the demand side.

As discussed previously, a catalogue falls in the category of an external transaction platform, typically led by an intermediary. Yet, the players behind the UK's platform programme fail to specify actor(s) who would be strategically best placed to perform the role of an intermediary. Informal discussions with P-DfMA experts revealed that public clients cannot take leadership of the catalogue, and CIH had no clear vision on who could take a role of an intermediary. This is mainly because the role of public clients, in terms of platforms leadership, is confined to setting the requirements for the components of product platforms and in demanding their use through the power of procurement (HMG 2020). Indeed, it is not ideal for a transaction platform to have an intermediary that also represents a demand side for the components. The role of the intermediary is to mediate value exchange between the two sides of the transaction platform, which are the demand side (clients), and the supply side (owners) of the product platforms (Gawer & Cusumano 2002; Iansiti & Levien 2004). Making the preceding critical delineations is important for the UK's platforms programme.

To clearly delineate who can/should play the roles of "leaders", "owners" and "intermediaries", the nature of the platforms itself should be addressed. The CIH (2021b, p.8) envisions that the digital component catalogue, a part of the platform, will enable the emergence of an ecosystem of co-specialised and complementary actors leading to "multiple product platforms in the market serving different market segments", and eventually creating "new markets". This espoused vision about an ecosystem indicates that there is an expectation for ecosystem growth around the catalogue. However, although transaction platforms can serve multiple markets, they are not ecosystems (for further reading, please, see Jacobides *et al.* 2018 Figure 2, p.2266). Rather, the growth of ecosystems and creation of new markets is a feature of innovation platforms and their ecosystems. As discussed earlier, an innovation platform is a business model where a platform is an enabling infrastructure for the growth of an ecosystem of complementarities (Jacobides *et al.* 2018). This is not the case for product platforms where owners are able to sell their offerings using a transaction platform, and their innovation efforts are independent from the transaction platform. Thus, transaction platform intermediaries mediate value exchange but do not coordinate value creation and capture processes between both sides. Their key role is to match the right demand with the right supply and enable transactions (Nambisan & Sawhney 2011). Establishing these critical distinctions between leadership for transaction, innovation and product platforms – and how they might operate – is a fundamental step that needs clarity for any meaningful gains to be realised from the UK's platform programme.

Platform governance

The CIH is clear about the need for a rulebook to direct autonomous product platform developers' efforts towards the needs of demand (see Table 3). Governance principles are discussed in the Platform Rulebook, albeit briefly (CIH 2022). The principles outlined are tailored as a "framework for accountability" to ensure that the Platform Rulebook remains a live document to ensure a continuous development of the platform from its Beta state. We find the policy documents merely outline aspirations and expectations without a clear indication of strategic leadership and how product platforms will be governed. Aspirational views of what is expected of owners (government and industry), custodians (impartial regulatory bodies) and users (including clients to test platforms and offer feedback) are also outlined. The problem, however, is the lack of clarity on what governance arrangements for framework accountability will be established beyond the concepts of openness, collaboration and continuous improvement to ensure the viability and "accelerated adoption of product platforms" (CIH 2022, p.49).

The understanding of platform governance identified from the documents is far from explaining strategic activities for aligning value creation and capture by participating actors as indicated in the academic literature (Nambisan and Sawhney 2011, Tiwana *et al.* 2010). Platform governance captures the capability of a firm to purposefully design and put in place decision-making mechanisms to encourage, direct and

enable the networks of autonomous actors to generate desirable outcomes (Nambisan & Sawhney 2011). Platform owners therefore have an important role to identify (mis)-alignments between the platform architecture, governance models and the environment (Tiwana *et al.* 2010). A challenge here, however, is achieving a balance between the control and autonomy of component developers and owners, making issues about intellectual property and shared ownerships corollary critical challenges (Eisenmann *et al.* 2006).

Another governance challenge compounded by the lack of specifics for the UK's platform programme relates to scaling up by intermediaries. These players might find it difficult to scale "their platform sides", as product platform suppliers will be hesitant to join unless there is a demand side. The government claims it would address this potential hesitation with a promised demand project pipeline of about £50billion (CIH 2021a,b). The scalability of the transaction platform to meet this need could be a critical challenge. The challenge of scalability is pertinent, considering observed failures of the government to fully follow through its own procurement policies meant to catalyse "technological innovations" (cf., Green 2021). Product platform owners might be unable to scale their solutions if demand is insufficient, and the demand side might not be able to find the right component if the supply side does not participate. This is a typical "chicken and egg" problem with transaction platforms that must be thoroughly examined by construction sector players and policy makers/adopters behind the UK platforms agenda. If the role of an intermediary is clearly defined, this problem could be addressed through governance mechanisms (another unclear aspect of the platforms agenda). A challenge for the intermediary to tackle would remain scalability if the demand side remains solely in the public sector. Creating demand for product platforms in the sector using the buying power of public clients can potentially lead to limited outcomes. The demand side will remain constant and at times scarce. That could create narrower and exclusionary networks between public clients and a few large firms supplying components, further deepening fragmentation in the construction sector.

Finally, from our analysis, the CIH (2021a, b) envisages, rather enthusiastically, that manufacturing firms will cooperate with supply chain firms to find new opportunities in the use of platforms (see Table 3). Within the loosely defined and inadequate platform governance framework identified, this expectation for autonomous actors to develop product platforms "creatively" is unlikely to deliver the espoused transformation in the long term. The construction sector's complex project delivery systems make it highly likely that product platforms will be owned or at least coordinated within alliances. That would foster the creation of additional tiers in an already fragmented sector; firms with greater resources would seek to exploit their capabilities to win greater platform component market shares. Related to this likely problem, SMEs might find it particularly challenging to stay competitive when incumbents and large firms enter their markets. This can further widen the gap between SMEs and large firms in terms of catching up with and benefitting from technological innovations.

Business models

The documents analysed show that there is an expectation for the emergence of new business models in an ecosystem organised around an open catalogue with components. The CIH (2021b, p.4) uses business models to refer broadly to "procurement and information management systems" (i.e. construction operating models) for project delivery. According to the CIH (2021a, p.6), sector stakeholders are of the view that platformisation will cause "*significant disruption to sector business models which might impact the appetite of some existing sector players*". In contrast, those who identified benefits saw product platforms as a means to create "*new business models [that will be] more profitable/equitable*" (ibid). The policy documents also recognise that the emergence of new business models requires a change in mindsets, culture and competencies within the supply chain, which all need time (CIH 2021a).

Platforms essentially support business model innovation and provide opportunities for the creation of new organisational forms (McIntyre & Srinivasan 2017). Business models articulate the logic behind the value creation and capture of an enterprise (Zott & Amit 2017). Value creation logic determines how business creates and delivers value to the customers while value capture determines the system of revenues, costs and profits required to deliver value to customers (Teece 2010). External platforms are new types of business models that enable emergence and growth of business models by their complementors based on specific logic. As noted earlier, platforms like Uber and Airbnb, operating in a business-to-customer (B2C) market, are a new type of business model which do not

change the business models of their supply and demand firms.

In contrast, however, the catalogue envisioned by the CIH for the platforms programme is for a business-to-business (B2B) market. This is a significant risk for the UK construction sector. Although B2B marketplaces are growing, they remain underexplored empirically, and there is no evidence that such marketplaces trigger disruptions in the business models of existing suppliers. We find no evidence from our analysis regarding how this can be achieved, and if it is possible at all considering that the marketplace is a catalogue which does not disrupt business models. The espoused expectation about the catalogue in UK policy is therefore merely aspirational, ungrounded in literature and inconsistent with empirical evidence. If the marketplace evolves towards an innovation platform, then perhaps there is the possibility of enabling emergence of new business models as evidenced in management literature (Gawer 2020). However, without a clear strategy on how to scale a catalogue's customer and supplier base, future chances of the catalogue becoming an innovation platform will remain slim.

From our analysis, the CIH (2021a) anticipates that the UK construction sector's existing business models will be a bottleneck for the emergence of a new ecosystem, as they have arguably been for other sector-wide technological innovation attempts (see Table 3). Considering the systemic struggle with strategic leadership, lack of capabilities to lead an innovation network and the complex context of sector, business models defined by the introduction of product platforms are likely to remain a bottleneck. Calls for business model innovation have been made repeatedly for several decades. These have been in areas including research and policy circles (Sui Pheng and Ke-Wei 1996), enterprise resource planning (Chung *et al.* 2009), partnering, alliances (Egan 1998, Latham 1994), lean construction (Howell 1999) and recently greater productivity using BIM (Kiviniemi 2011). These calls have led to barely any significant changes in how construction firms operate. There is a systemic lock-in, which Hall *et al.* (2020) term as a "mirroring trap" that hinders any form of transformative innovation in business models. The UK's P-DfMA initiative is therefore going to be subject to a long learning curve unless the structural sector-wide problems with existing business models are tackled, the strategic implications of platforms on dependent businesses are clearly understood and appropriate solutions are formulated.

Conclusion and implications

Conclusions

We conclude the preceding arguments, findings and discussion in this paper by highlighting the paper's contributions. Firstly, from our critical analysis we have extended existing views on product platforms. Most studies on product platform development are primarily concerned with two main areas; market segment and financial strategies (Muffatto & Roveda 2000, Robertson & Ulrich 1998, Simpson *et al.* 2001), and product platform design (Halman *et al.* 2003, Johannesson *et al.* 2017, Simpson *et al.* 2001). We have expanded this view by shifting focus from a single enterprise and product to an analysis of the relationship between product platform owners and the future business of a catalogue in the construction sector. In doing so, we have consequently argued that deploying product platforms in the sector needs a wider view of the platformisation agenda beyond what presently exists in policy, to embrace what is fundamentally followed in product platform literature.

Secondly, we have offered a clarified understanding of product platforms and DfMA. To this end, we drew on engineering, technology and innovation management literature and reflected on how product platforms have been amalgamated in the UK's ongoing "platformisation" agenda around the idea of P-DfMA. We differentiated conceptualisations of DfMA, product platforms and other types of internal and external platforms and discussed how product platforms and DfMA are adopted by firms for specific business needs. We have further identified key issues that need addressing if an incremental uptake and use of product platforms is to be achieved in the construction sector. The paper reveals a lack of articulation of platform types, insufficient engagement with management literature, and inconsistency in the use of terms in existing policy. The types of platforms suggested in the policy documents contain strategic and business organisation and technological implications and raise some critical questions. While the process of transformation from DfMA to product platforms is seemingly "natural" for many firms in other sectors (e.g. automotive and aerospace), a question that remains is why does the construction sector need to emphasise the platform approach to DfMA when the two design principles are adjacent and incorporate manufacturing and assembly principles? A related question for empirical investigation is how (if at all) construction firms pioneering P-DfMA in the UK have been able to expand their business to accommodate mass

customisation, scalability and flexibility using product platform design principles.

Based on the analysis of the UK's P-DfMA agenda presented, the questions accentuate the warnings of Bresnen and Marshall (2001, p.343) about the "value-laden nature of messages of change". Such messaging, they argue, can have detrimental impacts arising from subjective filtering of new management approaches if there is no rigorous engagement with theories but sole reliance on practical experience. Our analysis underscores Bresnen and Marshall (2001) warnings for the case of the P-DfMA agenda in the UK construction. The questions raised are pertinent given that for a long time, attempts to make construction "more like manufacturing" have not yielded the desired outcomes (Winch 1998, 2003a, 2003b, Sergeeva and WInch 2020). They are also useful for addressing a gap in literature about product platform implementation and management when it comes to their deployment for inter-firm organisation (cf. Halman *et al.* 2003). Furthermore, tackling these questions is also relevant for a better understanding of knowledge diffusion from other "best practices" into the construction sector (Bresnen & Marshall 2001). We have therefore sought, in this paper, to catalyse academic, policy and sector practitioner discussions about this risk in relation to the concept of P-DfMA, so that relevant and applicable ideas to bridge the gap between theories and practice might emerge.

Thirdly, the critique presented in this paper is not only relevant for the UK's ongoing platformisation agenda as part of largescale transformation attempts, but for any firm aiming to adopt product platforms in the construction sector. Although developments around platformisation in the UK are ongoing, our insights from this context can inform transformation initiatives elsewhere (cf. Seaden and Manseau 2001). This paper offers a starting point for critical empirical research into P-DfMA and product platforms and their implementation, specifically among scholars, businesses and policy makers in the construction sector. Doing so is crucial, as critical analyses of sector policy contribute to shaping innovation in construction (Seaden and Manseau 2001, Reichstein *et al.* 2005). Furthermore, by being UK-specific the paper offers a focused contextualised critique of important issues requiring attention from policy, practice and research angles regarding platforms in construction. Doing so, hopefully, contributes to and inspires critical discussions about product platforms in construction elsewhere.

In summary, reflecting on the sections above exposes how the idea of P-DfMA is a UK construction sector phenomenon that is not grounded in literature per se. Instead, the merged concept is mainly a product of discussions between a sector player and government-backed entities. P-DfMA, as adopted in UK policy, indicates that firms in the construction sector will need to embrace both product platform and DfMA design principles. It therefore plausible to argue that the CIH is seeking to establish DfMA to support product family design by pursuing P-DfMA. While P-DfMA encapsulates a combination of product platforms and DfMA, both are two distinct approaches and design principles although are complementary. They each require a consideration of strategic implications on firms' organisation and competition, as well as on the sector's context beyond the system architecture development. The P-DfMA agenda in the UK construction sector is an example of how platformisation in the construction sector in general warrants further investigation and juxtaposition with existing theories and empirical evidence.

Managerial implications

There is longstanding awareness by the government and players in the construction sector that the environment incentivises firms to preserve traditional business models (Egan 1998, Latham 1994, Aksenova *et al.* 2019, Hall *et al.* 2020, Zomer *et al.* 2021). Typically, new emerging technologies are diffused under the old ways of doing things (Miettinen and Paavola 2014, Zomer *et al.* 2021). However, P-DfMA requires different strategies for business innovation by participating firms. Firms operating in the sector will therefore need to consider not only their investment opportunity and market segment, but also the external environment, business and governance models, and revisit their own capabilities. Firms operating in the construction sector will need to develop the necessary competencies and capabilities for P-DfMA.

Beyond capacity building, product platforms require substantial investment by firms that can lead to better long-term business performance, compared to individually developed products (Meyer *et al.* 2020, 2018). Although government mandates are meant to stimulate firms' innovation, prevailing short-term thinking in investment can hinder the development of long-term visions. Participating firms in the sector can therefore anticipate productivity improvements from P-DfMA that will not necessarily lead to any widespread business model innovations. The current limitations of the

BIM technologies offered by mainstream vendors might hinder any evolution of product platforms in the sector. The firms should remain critical.

Policy implications

The UK government's push for P-DfMA in UK construction is clearly underpinned by large-scale public sector procurement. Currently, the P-DfMA agenda takes a top-down approach, placing a demand on firms to deliver product platforms within public sector projects (HMG 2020). A critical question that arises is: Can this approach lead to sector-wide transformation, considering that fragmented supply chain arrangements are still in place, even with projects that use BIM and Modern Methods of Construction (cf. Green 2019)? "Not quite" is our best answer for two reasons. Firstly, although public procurement will create a demand, firms might struggle to scale their solutions for public assets alone while profitable opportunities lie within the private sector. Here, the protectionist mindset underpinning the existing business environment is likely to incentivise against re-use of components across assets. Secondly, without consideration of strategic leadership, product platform architecture, governance and business models, the P-DfMA agenda is likely to be adopted under the mindset of "business-as-usual." This would have far-reaching implications. For instance, product platforms can pose a significant risk in the delivery of built assets if there is weak governance by its leadership. This risk can easily materialise in a sector like construction which is characterised by multiple players, and already suffering from significant leadership and oversight failures when it comes to building and materials safety (cf. Grenfell Tower Inquiry 2019). The Grenfell Tower fire in 2017 which caused 72 deaths, serves as a stark reminder and informs advocates of a P-DfMA approach to construction to be more critical in evaluating attendant potential risks. Specifically, this concern draws attention to issues around platform leadership, ownership and governance. These issues call for a policy re-think.

To summarise, we argue, echoing Miettinen and Paavola (2014), that the current P-DfMA agenda is a technology push and the questions raised are relevant. Lessons can be learned from the UK BIM mandate. Despite limited gains made, the policy has contributed to further fragmentation in a sector which, ironically, the government has consistently sought to integrate by pushing for greater use of digital technology (cf. Dainty *et al.* 2017, Green 2021). Without clear policy strategies to support firms to transition towards P-DfMA, there is a great risk of further fragmentation and a divide in the sector into firms that can/do work in a platform ecosystem and those that can/do not.

Study limitations and future research

Our critical review of UK construction sector policy and the P-DfMA agenda has revealed some questions that require attention by policymakers, and offer avenues for future research. These questions are summarised in Table 4. Based on the preceding sections, the questions are put forward to catalyse discussions in both research and policy circles around the issues identified about platform development, digitally designed components, platform leadership and ownership, platform governance, and business model innovation.

Furthermore, the questions in Table 4 are positioned to attract empirical research to clarify the theoretical underpinnings of platforms borrowed from other sectors for application in the construction sector, and how that plays out in practice. Given the lack of criticality behind the emergence of the P-DfMA concept in the UK construction sector, we hope that the questions will inspire relevant policy-informing research discussions.

Identified limitations of our paper also offer some directions for future research. Firstly, although our insights are derived from analysis of policy documents and literature, this is not new in critiquing ongoing policy-backed innovation attempts and raising critical questions for future studies in the sector (Seaden and

Table 4. Proposed future research questions.

Product platform development
• What are the core and periphery components around which the envisaged product platform will be developed?
• Will the core be developed in projects or the catalogue itself as an underlying platform?
• What strategic financial and market considerations will inform the development of the product platforms?
Digitally designed components
• What is the role of BIM in the P-DfMA agenda?
• What are the distinguishing features between BIM, Systems Integration and P-DfMA in the context of the platforms agenda?
• How can the marketplace avoid "lock-ins" and become an open or semi-open platform?
Leadership and ownership
• Who will lead and own the catalogue for the platforms agenda in the construction sector?
• Who will own / share risk in the use of the components for public projects?
• What approach will the platform owner take to lead its ecosystem?
Platform governance
• How will platform leaders manage the overall network of autonomous actors (via control, enabling or granting full autonomy)?
• How will platform leaders scale the marketplace in the public sector?
• How would sharing of components be incentivized?
• What measures should be implemented to address the raising concerns regarding the intellectual property (IP)?

Manseau 2001, Reichstein *et al.* 2005, Dainty *et al.* 2017, Green 2021). We have offered a detailed analysis of developments in the current UK construction sector policy agenda, similar to Green (2019), Dainty *et al.* (2017) and Oti-Sarpong *et al.* (2022), with a view to advancing critical discussions grounded in academic literature. In doing so, we have identified opportunities for further theoretical and empirical research at the nexus of construction sector policy analysis, technological innovation, and product platforms and DfMA literatures.

Secondly, this paper discusses developments related to product platforms in the context of the UK construction sector, which is a work in progress. Nonetheless, considering that global reports recognise the UK as one of the leading advanced economies in the implementation of technological innovations in construction, it is plausible that the issues raised for policy and research can hold lessons for attempts in comparable contexts (see: WEF 2016, WIPO 2020). Additional critical views from both advanced and emerging economies pursuing similar platformisation will be informative for construction engineering and management research.

Thirdly, from a policy standpoint, the development of UK product platforms requires a reconfiguration of existing institutional logics (cf. Oti-Sarpong *et al.* 2022). It will therefore be important to investigate how different firms operating in the construction sector would respond to the pressures arising from the need to develop and own product platforms in the public sector, particularly considering the implications for their business models. A multi-level analysis of the implementation of product platforms would offer insights about the interconnected developments needed at macro (wider context), meso (sector) and micro (project and organisation) levels to identify the bottlenecks and contradictions arising in transformation efforts.

In closing, it is worth cautioning that the policy expectation for the supply chain to reconfigure itself without strategic leadership, governance mechanisms and business model innovation can be a serious challenge for the sector. This challenge is further compounded by the sector's pervasive fragmentation, low interconnectedness, high uncertainty and multiple actors operating based on various self-preservation interests (Oti-Sarpong *et al.* 2022). Taking all the issues raised into consideration, the development of a platform for use in the construction sector requires a critical examination of overarching structural issues and how they can be addressed. Otherwise, the P-DfMA agenda will remain yet another technology push initiative with a less than promising future that might not lead to any significant changes.

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Notes

1. A global company of professionals (creative technologists, designers, architects, engineers, and analysts) offering sustainable design solutions for the built environment. The company self-identifies as a leader in the theory and practice of modern methods of construction (MMC), the Platform approach to Design for Manufacture and Assembly (P-DfMA) and automation in construction to deliver what is called design to value (https://www.brydenwood.com/)
2. Responsible entity for the product platforms programme in collaboration with government, construction sector and research partners.

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