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Manuscript title: Diffusion of Platform Thinking as an Innovation in the Construction Supply Chain

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Abstract

The construction industry has received long standing criticism over its fragmented approach to supply chain management, adversarial relationships, and ongoing defects. Platform thinking has been observed in other industries as a phenomenon that offers reinvention from the traditional perspectives on the supply chain. In this study, a scoping review of platform thinking is presented. A database search of 656 papers across 15 journals, along with 3 sources from a Google search and 12 sources from a manual review of the reference lists were reviewed in relation to platform thinking in construction. While many variants of platforms exist, the scoping review demonstrates a focus on product platforms that has historical precedents. This paper highlights the benefits of platform thinking whilst linking to the lessons of the past. This provides a valuable insight for future implications of platform thinking. This paper contributes to the limited literature on platform thinking in the construction industry by linking historical examples with present and potential future investigation.

1. Introduction

The uptake of industrialised construction systems and other modern methods of construction (MMC) has been slower than expected both within the UK and the rest of Europe (Brege et al., 2014). But as the global economy continues to recover from the effects of the Covid19 pandemic, there seems a renewed interest in industrialised construction and MMC as a means of driving productivity in the construction sector. For instance, existing challenges facing the UK construction industry have been brought into sharp focus because of the pandemic, leading to the publication of the CLC's recovery plan (CLC, 2020) for the sector. The plan has several key themes and ambitions over its two-year period, in particular the move to greater digital adoption and MMC. Linked to this vision is the concept of a product platform to drive the adoption of MMC (The Construction playbook, HM Government 2020, Mosca et al 2020, Thuesen and Hvam, 2011). The importance of product platforms has been acknowledged by the UK Government in the Construction Playbook (HM Government 2020) along with funding of trials by the Construction Innovation Hub to develop product platforms (Marshall, 2019). Alongside product platforms, the importance of digital platforms and ecosystems in construction are being recognised in Europe through the DigiPlace project (https://www.digiplaceproject.eu). Globally the use of digital platforms in construction are predicted to rise with increased investment from venture capital (Bartlett, *et al*, 2020) in digitally integrated solutions to the fragmented nature of the construction industry.

Despite the renewed interest in driving MMC through a platform approach, the successful delivery of projects using off-site production approaches will depend on the construction

supply chain (Wang et al., 2019). Pan et al, 2007 previously highlighted that the fragmented nature of the construction supply chain is a challenge to uptake in offsite construction and MMC. Also, the adoption and investment of innovative technologies and processes in the construction industry is low (Goulding et al, 2015) when compared to the pace of change in wider society (Farmer, 2016).

With the current emphasis and importance of platforms to the construction industry, it is key to understand how platforms relate to existing nomenclatures, technologies, processes and how platform thinking can diffuse within the predominantly traditional labour-oriented production model that presently characterises the UK construction industry.

The aim of this study is to explain platform concepts, the different motivations, challenges, and solutions that each variant provides to the UK construction industry and how such concepts may diffuse within the construction supply chain given its traditionally fragmented structure. In doing so, a scoping review of extant literature about platforms was carried out. To align existing knowledge processes with platform concepts, a configurational typology (Gerring, 2012) is proposed based on the knowledge gained during the research. Current literature appears to be limited in the applications of platform variants in the construction industry and their possible implications for the engagement and management of the supply chain. However, the key issue that still needs to be addressed is how these efforts will diffuse across the wider construction supply chain so that long term productivity benefits can be sustained. The characteristics of the construction industry (section 1) , the nature of the supply chain and its implications for the diffusion of platform thinking are discussed

(section 2). The research methodology is explained in section 3 and the findings are specifically explored in Section 4 followed by a discussion in section 5 on innovation and then followed by the discussion and conclusion of the study.

2. Construction supply chain and diffusion of platform thinking

The construction industry is characterised by fragmentation (Farmer 2016; BIS 2013; Blayse and Manley, 2004 ; Larsen and Ballal 2004), loose coupled networks assembled for individual projects (Myers, 2009 ; Chinowsky, 2008; Dubois and Gadde, 2002) and adversarial contractual arrangements (Farmer, 2016 ; BIS, 2013; Zaghloul and Hartman 2003). A Few large contractors are at the top of the industry (by size and turnover) with a large number of small firms at the bottom (CIOB, 2020; Hillebrandt, 2006). Annual construction statistics for 2018 indicate that over 95% of the firms classified as working in the construction industry employ less than 13 as shown in Figure 1.

This has led to an ongoing trend (Green, 2016) of bifurcation between the those the top of the industry becoming ‘integrators’ (Moreldge and Smith, 2013) of the multiple small contractors who physically carry out the production. This can be viewed as a consequence of the industry’s susceptibility to economic cycles. The allocation of work across multiple subcontractors allows the larger contractors flexibility and scale in response to the level of demand without taking on the risk themselves (Farmer, 2016; BIS, 2013). Training of the workforce, outside of legislative compulsion are left for each subcontractor to determine (Green, 2016; Morledge and Smith, 2013) creating the dilemma of “earn versus learn’ (BIS, 2013; Sexton *et al*., 2006). The labour model of the industry is further weakened by the

ongoing and future shortage of skills (CIOB,2020;CITB, 2019). Thereby the diffusion of knowledge throughout the supply chain is fragmented with the lack of investment in skills and knowledge being attributed to the construction industries perceived low levels of productivity and innovation (CIOB, 2020; Farmer, 2016; Nadim and Goulding 2009). Innovations such as MMC (including pre-fabrication and offsite production systems, design for manufacturing assembly) have sought over the decades to industrialise construction in response to these issues (Nadim and Goulding 2009). However, the adoption of such innovations remains low (Goulding et al 2015).

This situational context provides two dimensions for consideration. The first being the temporal relationship between actors in the supply chain for the duration of their contracts. The second being spatial where actors assemble at different geographical locations. Therefore, there is a continuous assembly and disassembly of the supply chain in different locations and contexts for each project.

The foregoing structure of the construction supply chain will have implications for the wider adoption of MMC. The platform concept is central for driving an industrialised approach to construction or MMC. Platform thinking has emerged as an approach for organising production and can help shift the production model in the construction industry from the current labour dominant model towards off-site production and other modern methods of production. At its core, platform thinking is considered a business model that moves away from linear concepts of supply and demand to market, product or a combination of perspectives. A business model is the logic and strategy that a firm uses to identify, create, and deliver value to

their clients/customers, alongside a viable revenue and cost structure that fits with their business priorities (Teece, 2010).

Business models for industrialised buildings and MMC have been evaluated in relation to market position, operational platform and offering (Brege et al., 2014, Lessing and Brege 2015, Lessing and Brege 2018). The offering comprises of whatever final value proposition that is offered in the marketplace to consumers the corresponding revenue model. Within the context of industrialised buildings, these will comprise of the final products and/or services, including after-sales services that are offered to clients. The market position relates to the identified market segment and role in the marketplace for which value propositions will be developed, and communicated, including the relevant broader value network of suppliers and partners. A satisfactory market position will be determined by market share, brand equity, customer satisfaction and profit margins (Brege et al., 2014). The operational platform comprises of how internal and external resources and competencies are organised to generate the value proposition that is offered in the marketplace. For industrialised buildings and MMC, such an operational platform will require the development of product or component product platforms that enables the relevant resource base (both internal and external) to be pulled together to create the final value proposition offered to the market (Brege et al., 2014). Lessing and Brege (2015), who focused just on product-oriented business models, questioned whether the development of a strategy for exploiting such models should be driven by an outside-in (exploiting markets 'and customers' demand) or inside-out approach (exploiting existing resources base). The two cases they analysed revealed an outside-in approach for which the

organisations also acted as both manufacturers and developers that controlled production in their own manufacturing facilities.

From the forgoing discussions, it can be argued that adoption of platform thinking in the construction sector could represent a significant milestone towards making industrialised construction and MMC a mainstream business model option for construction businesses and their wider supply chain networks and partners to adopt and exploit in generating value for clients in the marketplace. However, beyond the product-oriented perspective of platforms presented by Brege et al., 2014, Lessing and Brege 2015, Lessing and Brege 2018, questions still remain as to what other types of platforms exist for driving MMC and how platform thinking diffuse widely within the construction supply chain. The question on the typologies of platforms that exist is important given the range of meanings of this concept across different contexts and industries. The question of how the platform concept is likely to diffuse will help provide insight into how the current traditional labour-oriented construction supply chain that dominates the UK construction industry will evolve over time and how the construction supply chain can adapt their business operations accordingly.

3. Research methodology

Due to the conceptual and semantic ambiguity of the term 'platform' in the context of construction and the need to clarify key concepts and definitions in the literature the following research questions were formulated in response to the above:

- *Are there multiple variants of 'platforms' in use in the construction industry?*
- *How does the concept of 'platforms' relate to the construction industry and its*

industrial structure?

- *As an innovation how will the 'platforms' diffuse through the supply chain?*

In answering these research questions the methodology followed a literature review with 4 stages which is shown in figure 2.

The first stage was to identify target journals from which to explore the concept of platform thinking within the domain of the construction literature. The preliminary search was initially bounded by a targeted selection of top tier journals based in part on Wing (1997) and on Li et al. (2014), a frequently cited systematic review on the related subject of prefabrication and its management. There was concurrence between the Wing (1997) and Li at el (2014) on the following 6 publications; Automation in construction, Building and Environment, Building Research and Information, Construction Management and Economics, Engineering construction and Architectural Management, Journal of Construction Engineering and Management.

From Li et al. (2014) the additional 4 Journals were identified as being relevant to the subject area ; Habitat International, Journal of Architectural Engineering, Construction Innovation, Energy and Buildings.

In order to broaden the target journals the following 4 Journals were added to the selection Construction and Building Materials, PCI Journal, Engineering Structures and Journal of Bridge Building. These were chosen to explore if the concept of platform thinking was present within the materials (Construction and Building materials and PCI Journal) and engineering (Engineering Structures, Journal of Bridge Building. Literature. The sources are

shown in table 1

The second stage was to determine search criteria and search engine. Due its world class comprehensive Index (Li *et al,* 2018), The Clarivate Web of Science citation database (version 5.35) (Wos) was selected for preliminary searching of its core collection in preference to other databases such as Scopus or Google Scholar.

As part of the search strategy the results were not limited by a time frame to ensure that all possible contexts of 'platform' over time would be gathered. No further criteria were used to limit the number of articles. The term 'platform' in the topic field was searched throughout each of journals using the following search code:

TS=(Platform)

Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, Timespan=All years

The purpose of the keeping the search criteria so broad was to avoid the risk of biasing the results to any particular interpretation of platform thinking in the first instance.

Stage 3 was to review the articles retuned by the search (n=656) from the 15 Journals (search conducted 27/07/2020). The abstract was read for each of the results and exclusion criteria applied. The exclusion criteria used comprised of (a) articles not meeting the contextual meaning of platform as described on section 2 and (b) articles that related to other definitions of the term platform (such as 'working platform' in the case of scaffolding for example).

This greatly reduced the number of articles (n =10) that were considered as meeting the

criteria of platform in the context under consideration.

Stage 4 was a wider search of platform thinking in construction of sources that included books and 'grey literature' (2017) due toimited number of sources found required in stage 3. Using Google Search an interrogation of the internet was undertake using the same exclusion criteria described above. This resulted in three additional sources being discovered. A further manual search was carried out of the reference lists from the selected papers and Google Search results again using the exclusion criteria above. Through this further search, 12 additional articles were obtained. The results are summarised in the table 2 below:

4. Results

The results indicate a range of sources from journals (n=20), books (n=4) and an industrial digest (N = 1). The database search (n=10) reveals a prevalence of product platforms as the focus of the studies (n=5) or of an economic perspective on two sided markets (n=2). A variety of other platforms (open (n=1), methodological (n=1), technological (n=1) were also identified. Where an industrial sector could be identified from the sources, housing (n=4) was the dominant focus.

The Google search identified a variety of sources (journal (n=1), Industrial digest (n=1), book (n=1). These sources had a focus on product platforms (n=2) along with a review of multiple platform variants (n=1). Multiple construction sectors had been considered (n=2) along with housing (industrialised house building n=1). The manual review of the reference lists identified a variety of sources: journals (n=9), books (n=3). This enabled a link to be established between platform concepts and the diffusion of innovation both as its own concept

and within the construction industry. Consequently, some sources (n=5) did not contain a platform focus but are included in response to the research questions relating to innovation. Where a platform focus could be established, product platforms (n=2) and multiple variants (n=2) were dominate over the other forms (economic (n=1) organisational (n=1) ecosystem (n=1)). Extending the search through reviewing the reference lists also broadened industrial sectors being studied. Where a sector could be established, information technology and manufacturing (n=5) were the most common sectors with construction and construction consultancy (n=3) following and multiple industries (n=1). An overview of the findings across time are shown in Figure 3 below:

4.1 Platform thinking and a shift towards Modern Methods of Construction (MMC)

Platform thinking can relate to multiple industries and can be regarded to be a modern management phenomenon (Thomas *et al*., 2014). It has multiple definitions and applications. (Thomas *et al*., 2014 ; Gawer 2014). This is due to its theoretical principles arising from multiple industrial and market perspectives (Gawer,2014). The scoping review identified that platform thinking can be described by the separation of customer value and reduction of cost which targets flexible products or projects (Thuesen and Hvam, 2011). It seeks to capture economies of scale across product and projects (Bryden Woods and CDDB 2018 ;Thuesen and Hvam, 2011). This shares its organisational logic with the aspirations of MMC (Thuesen and Hvam, 2011).

In seeking to answer the research question on platform variants, 3 sources were found (Mosca , 2020 , Thomas *et al.*, 2014, Gawer , 2014) that sought to describe and consolidate

different platform types.

Mosca (2020) following the work of Thomas *et al.* (2014) and Gawer (2014) provides an alignment of multiple platform variants from Thomas *et al.,* (2014) to those expected to be found in the construction industry, which is summarised in Table 3 :

These are described in the following subsections.

4.2 Platform organisations

Platform organisations provide a structural perspective on how resources and capabilities are utilised at the level of the firm. This is a dualistic form of dynamic capability (Thomas *et al*., 2014) that separates routine organisational transactional processes from those supporting strategic changes in response to the external environment (Ciborra, 1996). This platform therefore allows for change in response to the complexity of the environment. The scoping review offers the separation of the main contractors relatively lean management from the supply chain of multiple actors as an example of platform organisation (Mosca *et al*., 2020).

4.3 Product platforms

Robertson and Ulrich (1987) define product platforms a collection of assets that are shared by a set of products. The scoping review revealed that product platforms arise from a manufacturing perspective (Mosca *et al*., 2020 ; Peltokorpi *et al*., 2018 ; Said *et al*., 2017). This requires a strategic decision on the market segment(s) to be served, the level of product predefinition at the interface with the client and matched against the internal resources and supply chain (Hall *et al*., 2020 ; Lessing and Brege 2018; Jansson *et al*., 2014; Thuesen and

Hvam 2011). There are four platform strategies associated with successful product platforms (Huang *et al*., 2005.) These are commonality, modularity, scalability, postponement.

Commonality relates to the to the standardisation of components that can be widely distributed but balanced against product variety (Peltokorpi *et al*., 2018). Modularity offers options on modules that have been standardised that can be combined and configured into different end products to meet the market demand (Peltokorpi *et al*., 2018). Huang *et al*. (2005) Identifies multifunctionality as a subset of modularity whereby modular options are designed to optimise the combination of multiple functions that are commonly used in a family of products (Mosca *et al*., 2020; Peltokorpi *et al*., 2018). The scoping review indicates that product platforms and modularity define the roles and boundaries between the actors in the supply chain (Peltokorpi *et al*., 2018)

Within the scoping review, Mosca *et al*. (2020) contends that the adoption of modular platforms has not been widespread in construction. However within the scoping review examples of its use were revealed (da Rocha *et al*., 2019; Peltokorpi *et al*., 2018; Ramaji and Mernari 2016 ; Jansson *et al*., 2014 ; Thuesen and Hvam 2011).

Scalability relates to the serialisation of and the ranging of product parameters that have to be changeable (Huang *et al*., 2005; Peltokorpi *et al*., 2018). Postponement relies on the late introduction of variety thereby avoiding the introduction of changes at the earliest stages of production (Huang *et al*., 2005). These strategies make a contribution to the ability of firms to offer mass customisation. Mosca *et al*. (2020) provide a generational platform strategy where changes between the products are designed to generational changes can be

accommodated according the probability of changes of components over time. This provides for a stable core offering, that develops peripheral features to meet demand.

These perspectives are advanced in the case of construction production in Bryden Wood and CDBB (2018) with a focus on components, productivity, and mass customisation. This in contrast with traditional construction which is one of constant reinvention. The scoping review highlights that the product platform offers a moderation between technological push and market pull factors by aligning the two extremes of the respective concepts (Hall *et al*., 2020 ; Lessing and Berge 2018)

4.4 Market intermediary platforms

The market intermediary platform acts as an interchange between two or more groups or producers with (Thomas *et al*., 2014; Gawer, 2014) users or clients. In essence is it an example of a two-sided market matching, supply with demand (Rochet and Tirole ,2003). The scoping review highlighted that this can lead to more efficient transactions by removing bottlenecks and for value to be captured through the use of platform (Mosca *et al*., 2020). The owner of the platform does not take ownership of the good or services that are produced. Mosca *et al*. (2020) points to online platforms that link the purchasers of bricks to suppliers as an example of this platform. It could be contended that contracting authorities within the public sector have developed to become market intermediaries ; Costa and Traveres 2013 ; Tennant and Fernie 2012).

4.5 Platform ecosystem

A platform ecosystem describes a network that operates around central focus or point of control (Thomas *et al*., 2014). Value is captured through the coordination of buyers and sellers through complementary assets services and technologies (Gawer, 2014). The platform ecosystem has evolved from organisational and product platform literature (Thomas *et al*., 2014). Its conceptual roots lie in the development of information technology and software.

The scoping review identified the use of digital technologies to manage workflow (Mosca *et al*., 2020) and to configure clients design as a part of an ecosystem that includes outsourced manufacturing and onsite assembly using the example of project frog (Hall *et al*., 2020). This offers the opportunity to drive greater interoperability between the actors in the network using the same platform (Costa and Traveres, 2012).

4.6 Platform design and governance

The involvement of third-party suppliers and the ability to integrate products, services and goods competently can be seen as measure of architectural openness (Thomas *et al*.,2014) while governance is dependent on integration and alignment between the platform owner and actors (Tiwana 2014).

Architecture can be seen as being on a continuum starting at the level of the firm only (a closed system) to industry wide Gawer (2014) or an Ecosystem platform (open) (Thomas *et al*., 2014). Selecting the right level of openness is key to the success of the platform as it requires the right level of participant adoption and value creation (Thomas *et al*., 2014). The scoping

review identified that the openness of the platform can be influenced by the organisational objectives of the companies involved and where they see their value propositions in relation to competition in the market (Hall *et al*. 2020; Lessing and Brege 2018; Jansson *et al*., 2014). A high degree of vertical integration of the supply chain can offer the faster deployment of technological change due to governance being held within the firm (Hall *et al*., 2020) In contrast an open system requires greater flexibility for design and the supply chain as greater variability is introduced (Jansson *et al*., 2016) consequently more time is needed to co-create products with long term partners. (Hall *et al*., 2020; Lessing and Brege 2018)

Platform organisations or product platforms can be seen as having limited openness relating to the internal contributions from within the firm (Thomas *et al*., 2014)

Other platforms may exhibit a many to one relationship which is open to third-party participants subject to some restrictions, which could be considered to be semi-open (Thomas *et al*., 2014).

Many to many platforms relate to the openness of the platform to both supply and demand sides to third parties with a few if any restrictions on the third-party participants in development and commercialisation. Thomas *et al*. (2014) identifies that many to many relationships can be observed in both ecosystem and market intermediately platforms.

4.7 Platform design dilemmas

The architecture of a platform can lead to a series of dilemmas that require resolution in order to be successful (Tiwana 2014). Mosca *et al*. (2020) and Tiwana (2014) highlight the chicken and egg dilemma whereby the platform cannot attract enough suppliers unless it has

enough end users and not enough suppliers because of the lack of end users. Leaving this issue unaddressed will result in the platform failing (Mosca *et al*.,2020) ; Tiwana ,2014). Mosca *et al*., (2020) and Costa and Tavares (2012) pinpoint that market intermediary platforms can suffer from this, while Tiwana (2014) also warns that platform ecosystems can also be affected by the same dilemma.

Demand side inertia can present a further dilemma that diminishes any positive network effects that may be gained while end users stall in in the uptake of the platform. This can be even more so if users are already engaged or invested in an existing platform.

Emergent innovation that advances the platform ecosystem cannot be predicated and planned. However, it will not arise unless enabled and shaped effectively by platform owners who need to be cautious about curtailing it (Tiwana, 2014) this is the control dilemma.

The focus of platform design and alignment revolves around or what supplier should achieve rather than interference in how it is achieved (Tiwana, 2014).

The ease by which a supplier or component and removed from the platform, replaced or upgraded without being a detriment to the wider platform is the dilemma of intricate dependencies (Tiwana , 2014). This includes the level of intervention required by the platform owner to make any such changes successful. This raises the question of governance and whether changes can be made without the need to directly interact with the platform owner or other suppliers.

Responding to complexity both technologically and economically is the mirroring dilemma. (Tiwana, 2014). As the user base expands or contracts adaption to either

architecture or governance is needed to maintain alignment Tiwana (2014). The scoping review identified this dilemma for vertically integrated solutions with consequences of suboptimal solutions that place capital investment in factory production at risk (Hall *et al*. 2020).

The initiation and implementation of platforms can be described as 'diffusion' (Lundberg *et al*., 2019). How this takes place is dependent on the characteristics of the industry, and multiple social networks acting across multiple dimensions such as firm size and time (Shibeika A and Harty C , 2015 ; Rogers, 2005, Rogers 1995)

5. Diffusion of platform thinking as an innovation in the supply chain

Innovation is a high-level concept that is distinguishable from invention in that it is the actualisation of idea(s) that confers some benefit (Shelton *et al*., 2016 ; Johnson *et al*., 2008). Sexton and Lu (2010) highlight that the reduction of innovation into a single definition with its inherent contradictions, is a pointless exercise. The challenge of doing so can be described as hermeneutic (Gerring, 2012). Over time views have developed through the conceptual difficulties of the 'technology push' and' market pull' (Zwardie 2010 ; Johnson *et al*., 2008). The role of technology in innovation forms the basis for new products, processes that can shape the market itself while market pull concept sees consumer requirements as the key driver to pull innovation from the market (Johnson *et al*., 2008).

The diffusion of innovation can be described as how an innovation is dispersed and propagated through society (Rogers ,1995). It is therefore a process by which the adoption of an innovation may be initially adopted by a small number of members of a societal network with wider adoption throughout the network taking place over time (Valente, 1996). Previous

research has indicated the importance of network structures in playing a moderating role between network effects and diffusion (Choi *et al*., 2010). Sheibieka and Harty (2015) and Rogers (2003) distinguish that diffusion in organisations is more complex that is its amongst individuals. Diffusion in organisations allows for multiple paths for diffusion (co-evolutionary complexity), relational complexity, temporal complexity and cultural complexity (Sheibieka and Harty, 2015). The dynamics of communication take place through the multiple actors through the various internal and external networks, across and within firms (Choi *et al*., 2010; Chinowsky *et al*., 2008). Diffusion is also contingent on the size of the firm (Rogers 2003). Sexton *et al*. (2006) observed that industrial characteristics of the UK construction industry restrict large scale innovation and that small construction firms are limited in their ability to adapt due to their limited relationships and networks. In contrast, large construction firms operate in complex, dynamic markets that require company complexity with wider and longer strategic horizons. What is suitable for large firm may be unsuitable for small firms (Wipulanusat *et al*., 2019). Diffusion can take place over years or decades depending the context. Sexton *et al*. (2006) observed digital adaption by SME's was focused on short strategic horizons (months). Whereas Lundberg *et al*. (2019) found the adoption of product platforms at the level of the construction firm were yet to be fully implemented throughout the social system after 10 years.

6. Discussion

The scoping review identified multiple variants of platforms from which different concepts, methods and techniques and solutions emerge to resolve different challenges. To emphasise

and distinguish between the platform variants the following configurational typology (Gerring 2012) is constructed using the findings of the scoping review in section 4 as shown in Figure 4

Within in the findings of section 4, 4 variants of platform were uncovered with broad agreement between in the literature as to their conceptual basis. This is represented as a subdivision of the platform concept created primarily from Mosca et al (2020) and Thomas et al.(2014). The further diminished subtypes of the product platform variant are created from the 4 strategic positions and the subset of multifunctionality observed by Huang *et al*., 2005.

The above typology illustrates that the limited literature indicates a focus on product platforms in the construction industry. Historically in the public sector use of standardisation and peripheral customisation can be demonstrated using system and modular construction in the production of housing and schools (Wright 2015; Kucharek 2012; CIRA 1999). The Consortium of Local Authority Special Project (CLASP), over its lifetime produced a series of generational designs from the late 1950's to early 1990s (Wright 2015 ; Kucharek 2012; CIRA 1999). The design adopted a standard spatial grid with a range optional finishes and fixtures which demonstrates historical parallels with a product platform as attested by Honikman (1966 : p.595) :

> "There is no doubt that an industrialised building system (1) can be flexible enough to cover a range of building types, (2) need not impose itself on architectural character and expression, and (3) can be modified without negating its cost and speed of erection advantages. Furthermore, as the flexibility increases so the system becomes less of a system and more of a method of building".

A more contemporary example and successor to CLASP is the 'Sunesis' system (Kucharek 2012). However, history has shown that poor quality implementations on site can have long lasting and wide-ranging consequences for industry and society such as the mass use of system buildings of the ranging from 1950-60s (BRE, 1985).

The instability of relationships in the construction industry where participants are regrouped to form project teams (Chinowsky *et al*., 2008) adds further complexity (Larsen and Ballal, 2004) which may be overcome by the repeatable nature of the product platform. Repeated use of network actors coupled with standardised design has been shown to have positive outcomes (Pryke, 2005). This is especially the case if the architecture of the platform is closed, and the network is initially limited to actors who can provide assurance of quality from the product platform. From this perspective on product platforms posit 1 is offered as:

Posit 1: The construction industry will adopt closed product platforms for new build construction initially in preference to any other type

The product platform is already being used to some extent within the industry and supported by the UK government with a £72 million investment in the UK innovation hub investigation into product platforms and assemblies (Marshall, 2019). In keeping with the past, the Government has indicated its preference for the product platforms in the procurement of £3 billion modern method of construction framework primarily focused on new schools (Lowe, 2020).

More openness may be introduced when product platforms are stable and the actors in the supply chain are able to meet the requirements of the platform governance.

The role of market intermediary platforms has been seemingly client driven out of legislative necessity such the formation of Contracting Authorities procure goods and services on behalf of other parts of the public sector (Morledge and Smith 2013 ; Parker 2016,), This creates value to contractors as it reduces the volume of ongoing tendering for contracts and reduces the repetition of procurement for similar projects across multiple public sector clients (Morledge and Smith 2013

Mosca *et al*. (2020) identifies the potential for this platform to support the circular economy. However, there is nothing to suggest that platforms cannot transcend their typologies (Thomas *et al*., 2014, Hall *et al*., 2020) to offer solutions that combine the attributes of one or more platforms. Therefore posit 2 is offered as :

Posit 2: Market intermediary platforms will emerge and develop to link both supply and demand sides of product platforms when these platforms become brands that are associated with their value proposition.

The network effects of the market platforms may assist in the diffusing innovation. The inter-connectedness of platform owner, user and supplier allows an established communication path between the actors. The role of digital technology has been growing in the management and coordination of the construction process. Historical digital communication and control has been missing from the process. A digital platform that can coordinate the process at the communication through the network of actors has much to offer the industry and the burdening use of platform ecosystems indicates a future direction. Therefore posit 3 is offered as:

Posit 3: Platform ecosystems will develop through time in response to the development of

product platforms and offer the means to manage the lifecycle of the product and in doing so will create competitive advantage amongst product platforms.

The use of Building Information Modelling (BIM)and Graphical Information Systems (GIS) have been used shown to offer the promise of efficient SCM which is limited by semantic interoperability between systems (Irizarry *et al.*, 2013). This is of critical importance to the construction industry as evidenced by the Digiplace project, currently endeavouring to create a platform for construction in Europe with a consortium of 19 partners (including representation from SME's) from 11 countries (Quintieri, 2019). The platform seeks provide a collaborative tool kit useable for all stakeholders including SME's that Integrates the lifecycle of built assets and links to public procurement platforms (Saa , 2021). Hall *et al.* (2020) observed the nascent application of the platform ecosystem in project frog and its potential for holism within the construction industry.

7. Implications

A greater use of product platforms would be a move to a process of assembly rather construction. This may start to address shortages of traditional skills (CLC, 2020). This has implications for those parts of the industry concerned with refurbishment and maintenance and more specifically heritage assets which have legal controls on repairs and refurbishment. The use of product platform will not help to address these shortages and in fact may exacerbate the issue in the long term. A move away from traditional skills also presents opportunities for new entrants into the construction industry. Evidence of the start of this trend can be seen by the number of non-traditional construction companies being placed on the Governments new

schools' framework (Lowe, 2020).

How SME's will interact with platforms has multiple implications. The view of platform owners in relation to SCM, architectural openness and governance structures will influence the role of SME's. Some evidence indicates market intermediary platforms such as contracting authorities and framework agreements are too burdensome and complex for SME's to adopt resulting fewer SME's gaining successful access (FMB, 2013). Digital technologies also have further implications for SME's as demonstrated by Sexton *et al*. (2006). Unless these have clear and demonstrable benefit without the need for implicit knowledge then SME's will be reluctant to change. The implications of not adopting the innovation will be the possible lack of market access (Peltokorpi *et al*., 2018). However, the negative corollary is that the lack of supply chain actors will result the lack of critical mass for any variety of platform that cannot meet demand. Furthermore, the quality and conformity of platforms is critical to maintain reputational value as history demonstrates.

8. Conclusion

This paper provides a typology of platforms despite current prevalence of product platforms in existing literature on platforms in construction. This may be due to the familiarity of this variant of platform and the long history of incorporating offsite and manufacturing production. There is evidence of platform thinking in construction since at least the 1950's. While the term 'platform' may not have been used, the attributes of product platforms have been present. The UK government has shown renewed interest in the product platform to deliver its schools programme along with the investment into the UK Innovation investigations into product

platforms. Unlike Government programmes of the past there is a greater prevalence of digital technology available to coordinate design and the interaction of the supply chain. The adoption of platforms will be in part dependant on the success of products in delivering the programme (proven track record) for both clients and the supply chain. The level of labour on site will need to change in response to the restrictions imposed by Covid-19. To that end the product-platform shows potential with the UK with Government prepared to support this variant. How this will diffuse over time is difficult to predict as product platforms have been with us for some time. Previous research into diffusion of product platforms at the level of the company indicates that the process takes place over years albeit based on limited case studies.

The other variants of platform are yet to have a developed body of construction literature yet there are limited examples of their use. Due to these limitations this paper provides 3 posits on the development of platform thinking that transcends the typology of platforms. The overall benefits of platform thinking is the realisation of value for both supply and demand sides of the construction industry. Further study of platform thinking, their respective typologies and how their adoption takes place within in the industry is required as this research is limited to the confines of the literature and theory.

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Table 1. Table of selected journals

Journal
AUTOMATION IN CONSTRUCTION
BUILDING AND ENVIRONMENT
BUILDING RESEARCH AND INFORMATION
CONSTRUCTION AND BUILDING MATERIALS
CONSTRUCTION INNOVATION-ENGLAND
CONSTRUCTION MANAGEMENT AND ECONOMICS
ENERGY AND BUILDINGS
ENGINEERING CONSTRUCTION AND ARCHITECTURAL MANAGEMENT
ENGINEERING STRUCTURES
HABITAT INTERNATIONAL
JOURNAL OF ARCHITECTURAL ENGINEERING
JOURNAL OF BRIDGE ENGINEERING
JOURNAL OF CONSTRUCTION ENGINEERING AND MANAGEMENT
JOURNAL OF CONSTRUCTION ENGINEERING AND MANAGEMENT-ASCE
PCI JOURNAL

Table 2. Table of selected sources

Search type	Publication type	Author (Year)	Source Title	Study type	Platform Focus	Country of study	Industry Sector
Database search	Journal	Costa AA and Traveres LV (2012)	AUTOMATION IN CONSTRUCTION	Case study	Economics	Portugal	NA
Database search	Journal	Costa AA and Traveres LV (2013)	AUTOMATION IN CONSTRUCTION	Theoretical proposal	Economics	Portugal	NA
Database search	Journal	Said HM , Chalansani T and Logan S (2017)	AUTOMATION IN CONSTRUCTION	Investigative Study	Product Platform	NA	NA
Database search	Journal	Jansson G Viklund E and Lidelöw H (2016)	AUTOMATION IN CONSTRUCTION	Case study	Open platform	Sweden	Industrialised house building
Database search	Journal	Lundberg M, Engström S and Lidelöw H (2019)	CONSTRUCTION INNOVATION-ENGLAND	Case study	Product Platform	Sweden	Industrialised house building
Database search	Journal	Peltokorpi A and Olivieri H and Granja AD and Seppänen O (2018)	CONSTRUCTION MANAGEMENT AND ECONOMICS	Case study	Product Platform	Brazil. USA. Finland	NA
Database search	Journal	Hall DM, Whyte JK, Lessing J (2020)	CONSTRUCTION MANAGEMENT AND ECONOMICS	Comparative case analysis	Product Platform	USA	NA
Database search	Journal	da Rocha CG , Ghoz H.B.C.E, Guadamin S (2020)	ENGINEERING CONSTRUCTION AND ARCHITECTURAL MANAGEMENT	Design science research	Methodological Platform	Brazil	Low income house building
Database search	Journal	Ramaji IJ and Memari AM (2016)	JOURNAL OF CONSTRUCTION ENGINEERING AND MANAGEMENT	Theoretical proposal	Technology	USA and Sweden	NA
Database search	Journal	Lessing J and Brege S (2018)	JOURNAL OF CONSTRUCTION ENGINEERING AND MANAGEMENT	Case study	Product Platform	UK	High rise student housing
Google search	Industrial Digest	Mosca et al (2020)	TRANSFORMING CONSTRUCTION NETWORK PLUS	Literature review	Multiple variants	NA	Multiple construction sectors
Google search	Journal	Thuesen C and Hvam L (2011)	CONSTRUCTION INNOVATION	Case study	Product Platform	Germany	Industrialised house building
Google search	Book	Bryden woods (2018)	NA	NA	Product Platform	UK	Multiple construction

							sectors
Review of references	Journal	Thomas LDW, Autio E and Gann DM (2014)	ACADEMY OF MANAGEMENT PERSPECTIVES	Systematic review	Multiple variants	NA	Multiple Industries
Review of references	Journal	Ciborra (1996)	ORGANIZATION SCIENCE	Case study	Organisational Platform	European	Manufacturing
Review of references	Journal	Gawer A (2014)	RESEARCH POLICY	Theoretical proposal	Multiple variants	NA	Information Technology and Manufacturing
Review of references	Journal	Robertson D and Ulrich K (1998)	SLOAN MANAGEMENT REVIEW	Discussion	Product Platform	USA	Manufacturing
Review of references	Journal	Rochet J and Tirole J (2003)	PLATFORM COMPETITION IN TWO-SIDED MARKETS	Theoretical proposal	Economics	NA	Information Technolgy
Review of references	Journal	Shibeika A and Harty C (2015)	CONSTRUCTION MANAGEMENT AND ECONOMICS	Case study	NA	UK	Construction Consultancy
Review of references	Journal	Larsen, G.D. and Ballal, T.M.A. (2005)	CONSTRUCTION MANAGEMENT AND ECONOMICS	Case study	NA	UK	Construction
Review of references	Journal	Larsen GD (2005)	CONSTRUCTION MANAGEMENT AND ECONOMICS	Theoretical proposal	NA	UK	Construction
Review of references	Journal	Huang GQ, Simpson TW and Ii BJP (2005)	INTERNATIONAL JOURNAL OF MASS CUSTOMISATION	Editorial	Product Platform	NA	Manufacturing
Review of references	Book	Rogers EM (2003)	NA	NA	NA	NA	NA
Review of references	Book	Rogers EM (1995)	NA	NA	NA	NA	NA
Review of references	Book	Tiwana (2014)	NA	NA	Platform Ecosystem	NA	NA

Table 3. Typology of platform types

Typology (Thomas et al 2014)	**Typology (Mosca et al 2020)**
Organisational	Platform organisations
Product Family	Product platforms
Market intermediary	Market intermediaries
Platform Ecosystem	Platform Ecosystem

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Figure 1. Size distribution of construction firms based on number of employees (source: ONS, 2018)

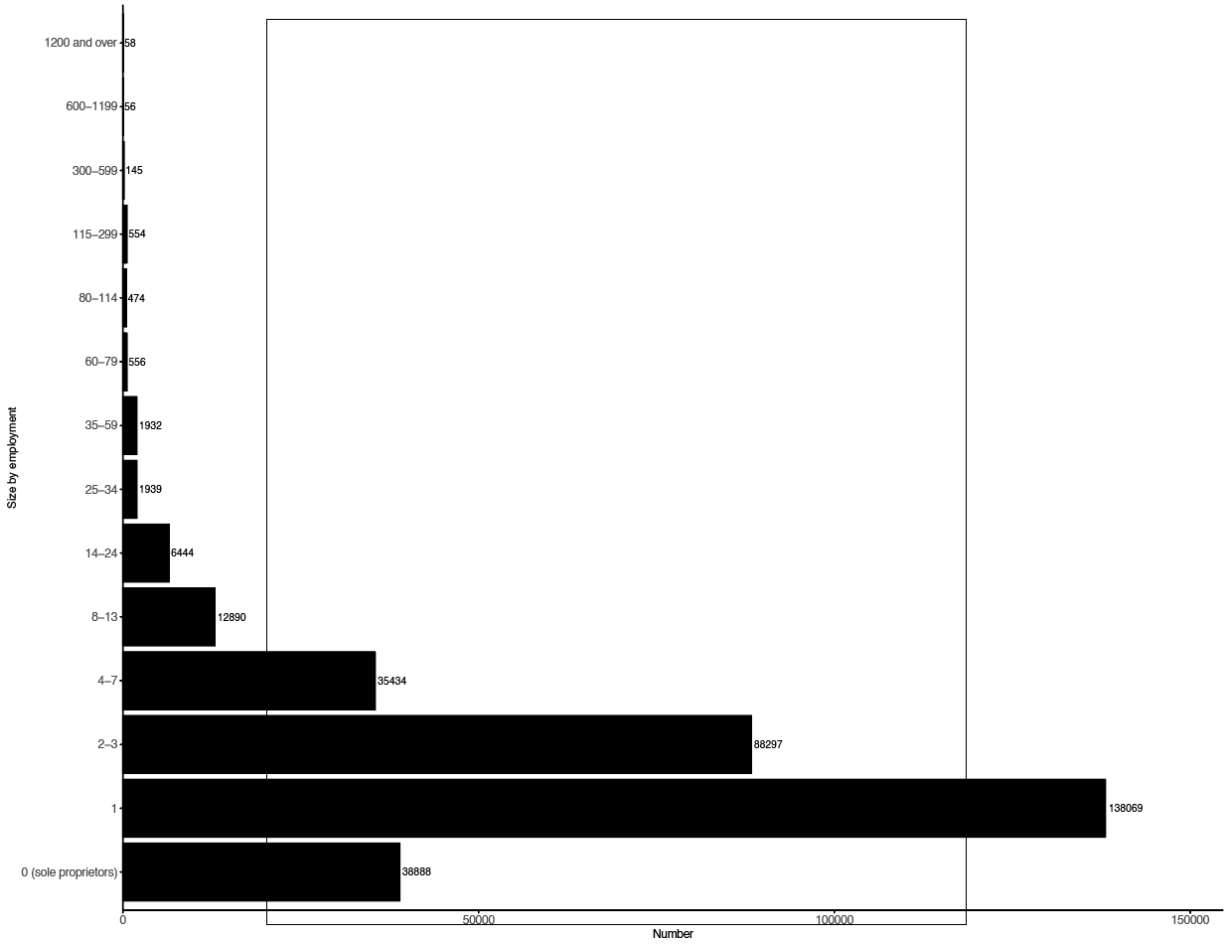

Figure 2. Process of source selection

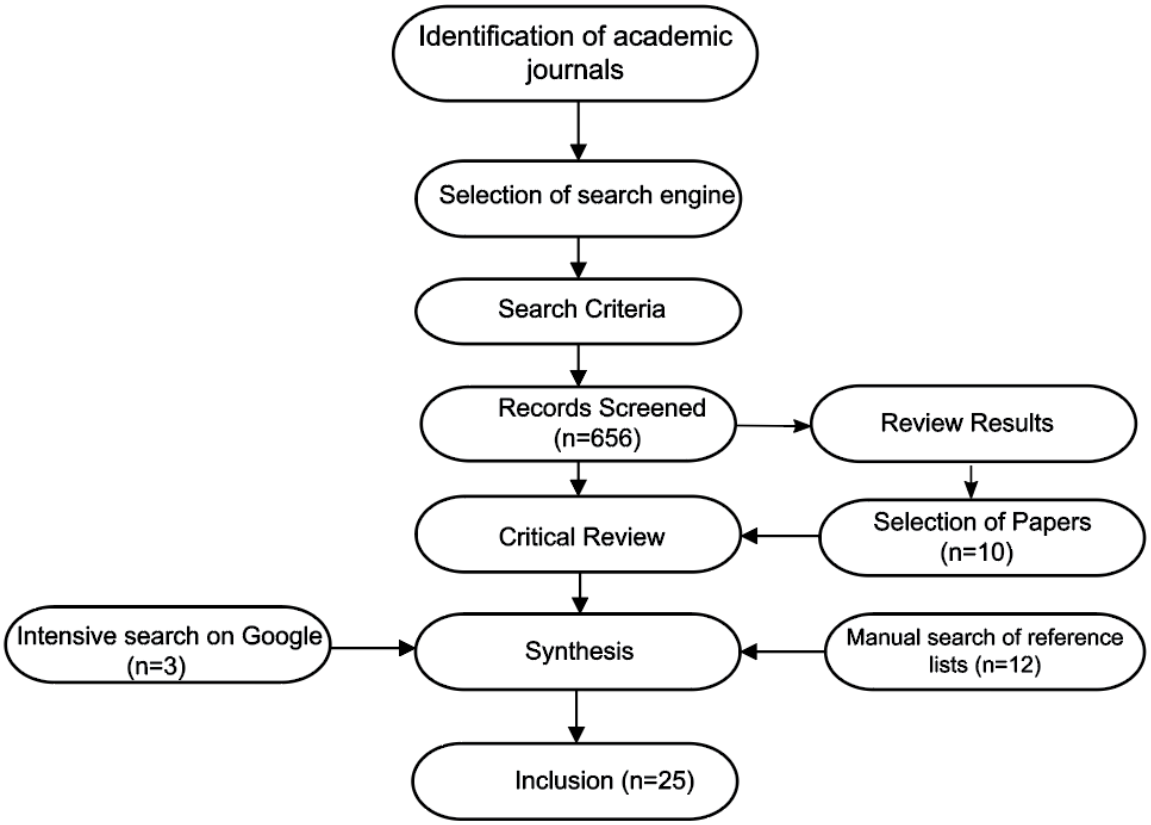

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Figure 3. Overview of platform focus across time for selected sources (by number)

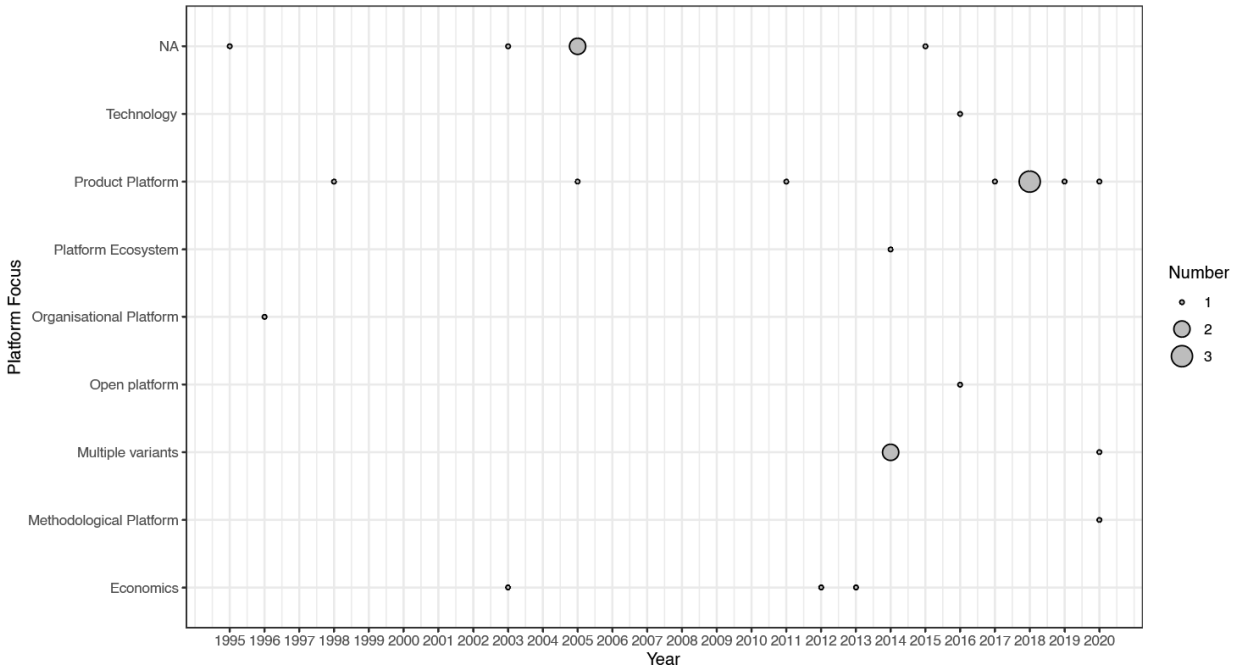

Figure 4. Typological structure of platforms (source: Mosca 2020 ;Thomas et al 2014; Huang et al 2005)