OFFSITE MANUFACTURING AND CONSTRUCTION INDUSTRY TRANSFORMATION: A MULTI-LEVEL SOCIOTECHNICAL TRANSITIONS PERSPECTIVE

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Offsite manufacturing (OSM) is currently one of the innovative approaches for construction that is at the forefront of industry transformation initiatives. Despite its espoused benefits, OSM is yet to become mainstream. Adoption of OSM in the UK is currently limited to discrete attempts at organisational and project levels. In this paper, the multi-level sociotechnical transitions (MLS) theoretical framework is used to review and synthesize relevant literature to conceptualise how an industry-wide uptake of OSM rests on the creation of a dominant platform around which other innovations will coalesce, in order to 'break through' and trigger changes in the existing configurations defining the way the construction industry works. To create step changes in the industry through widespread use of OSM, the paper highlights the government's role as a 'strong' actor in developing the UK's platform approach into a stable innovation to propel a reconfiguration of the existing sociotechnical regime. Beyond this 'top-down' techno-centric solution, the need for its co-evolution with policy, construction market dynamics, actor practices and existing technologies are drawn out in conclusion. The dynamics of these co-developments is identified as a direction for future research.

Keywords: multi-level, offsite manufacturing, sociotechnical transitions

INTRODUCTION

The UK construction industry is often berated for poor productivity, delayed projects, a slow work pace, unsafe work practices and for delivering projects that exceed planned costs (Farmer, 2016; Wolstenholme, 2009). These problems are partially attributed to the industry's lack of innovation and fragmentation (HM Government, 2013, 2018). The challenge, therefore, has been to find ways of transforming the industry in order to deal with these 'ills' by improving productivity, safety, timely delivery and cost-effectiveness. In the past three decades, there has been a gradual shift of government-led reforms to improve the industry - from more management-focused approaches that sought to gel the industry together by promoting collaborative practices, to more technology-centred initiatives incorporating a mix of coercive and voluntary measures (Dainty, Leiringer, Fernie and Harty, 2017). Mandating the use of building information modelling (BIM) on all public sector projects is an example of the former (IPA, 2016), and the decision of the government to give a presumption in

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favour of the use of offsite manufacturing (OSM) for project delivery links with the latter (IPA, 2019). These reform initiatives, however, are yet to produce the key performance goals that underpin their implementation.

More recent efforts at industry transformation by the UK government focus on changing the industry's practices from 'traditional' approaches to 'modern' methods of construction (MMCs), with the uptake and use of OSM and digital technologies (e.g. BIM) at the forefront (HM Government, 2018). Government Construction Strategies (Cabinet Office, 2011; IPA, 2016), Industrial Strategies (HM Government, 2013; 2018) and a Construction Leadership Council (CLC)-backed review of the sector's labour model (Farmer, 2016) underpin the growing emphasis on MMCs and OSM in particular. The latest Industrial Strategy (IS), 'Construction Sector Deal' outlines government's partnership with industry to promote the use of digital technologies and OSM in attaining goals including reducing construction and whole lifecycle costs by over a third, and halving delays of construction projects and greenhouse gas emissions by 2030 (HM Government, 2018). Supporting the government's effort to promote an industry-wide use of OSM is the vision to create 'a sector that can build new homes in weeks - and even days - rather than months; that can deliver new buildings at a third of the cost; that can provide affordable, energy efficient homes' (ibid, p.3). Tied to the reform agenda, Farmer's (2016) review of the UK construction labour model prescribes solutions including an increased use of OSM to solve the industry's productivity and labour problems.

Realising any meaningful industry-wide transformation is linked to the co-evolution of factors (e.g. user practices, technologies and policy) that define an existing configuration of preferred practices (cf. Orstavik, 2014). To modify such wide-reaching configurations, we argue, requires an initial amalgamation of micro-level developments to trigger a widescale use of OSM. Achieving this requires the implementation of well-coordinated government-industry initiatives focused on amalgamating discrete organisational and project attempts around a single innovation. This, we subsequently argue, holds the potential to trigger the transformation of the construction industry with OSM at the forefront. Using the multi-level sociotechnical transitions (MLS) theoretical lens, we conceptualise the construction industry transformation agenda as comprising multifaceted sociotechnical developments and highlight how achieving 'niche cumulation' holds the potential to trigger the desired step changes. We subsequently discuss how the UK's platform approach for OSM holds the potential to, by co-evolving with the sociotechnical regime of the industry, accelerate developments that could lead to the desired industry transformation envisioned in the government's reform documents.

The paper begins by situating OSM within the wider UK construction industry transformation agenda and how its espoused benefits underpin initiatives promoting its use. Next, the industry reform agenda based on a widespread use of OSM is discussed, with emphasis on the need for focus on micro-level developments in order to achieve the wider changes envisaged. This is followed by discussing how the MLS view applies to conceptualising the OSM-focused industry transformation agenda as a sociotechnical innovation. After presenting the review-based research method, attention is turned to the important role the government - as a strong actor - can play to trigger the co-evolution of aspects of the existing industry regime towards the envisaged transformation. Using concepts from the MLS theoretical framework, the UK government-led platform approach is conceptualised as a key development needed to drive step-changes in the way the industry works. The concluding remarks highlight potential pathways the process of transformation could follow and identify policy implications and directions for future research.

Offsite Manufacturing and the UK Construction Industry Transformation Agenda

Offsite manufacturing (OSM) generally refers to an innovative approach to construction involving the production of non-volumetric (non) structural components or volumetric units in a factory for subsequent installation in their final positions in a structure on site (Goodier and Gibb, 2007; Ågren and Wing, 2014). OSM is also referred to as offsite construction, modular integrated construction, or design for manufacture and assembly (Abanda, Tah and Cheung, 2017). Regardless of terminology, a fundamental principle of this method of construction is to move as many 'conventional' construction activities typically executed in-situ to a regulated factory environment in a place different from the final project site. This includes having a significant number of (non) structural components such as reinforced concrete walls, floors, columns, bathroom and kitchen fittings and balconies ready-made in factories and later installed in their designated locations on site, instead of being made in-situ (Goodier and Gibb, 2007; Ågren and Wing, 2014; Abanda *et al.,* 2017). Adopting such an approach to undertaking construction projects, therefore, requires changes to processes of design, procurement, planning, on-site tasks execution, and supplier and inter-organisational networks that have been developed to align with established and preferred ways of project delivery (cf. Ostarvik, 2014).

Although considered a 'modern' construction method, OSM has been in use for several decades, dating to post-World War 2 times when housing provision was a pressing need (NHBC, 2019; Ågren and Wing, 2014). Anecdotal evidence suggests that using OSM for construction can improve planning, cash-flow forecasting, productivity, safety, waste-reduction, timely delivery and lead to lesser environmental disruption and cost savings as there is more certainty associated with the method (BCG, 2019; Abanda *et al.,* 2017; House of Lords, 2018). According to KPMG (2016, p.3), using OSM "offers an alternative to this current construction status-quo by promising transformative improvements across the asset lifecycle in time, cost, quality and health and safety", creating benefits that accrue to different parties, including contractors, clients, manufacturers and end-users (BCG, 2019). Owing to the benefits OSM promises, the recent IS and government strategies place it at the centre of the reform agenda, alongside the use of digital technologies. Achieving targets of improved construction speed, minimised waste and reduced disruptions in work plans through a widescale uptake of OSM, the policy documents suggest, will address the construction industry's ills and accrue benefits to the government in the provision of more schools, hospitals, custodial facilities, and more houses at faster and cheaper rates to tackle the housing shortage in the UK (HM Government, 2018; IPA, 2019).

Achieving an industry-wide uptake of OSM as part of the reform agenda requires multi-layered adjustments to the established and preferred ways of delivering construction projects. Like other industry reform attempts - e.g., digitalisation through the mandatory use of BIM - the changes would, in turn, impact on actors (Dainty *et al.,* 2017), established connections between existing structures and their links into the wider socio-economic context. To achieve the reform goals, government policies and industry reports propose broad recommendations focused on changes to industry leadership, training, government-client-industry integration, and investment in research and development (Farmer, 2016; HM Government, 2018). Given the enthusiasm surrounding the transformation of the wider construction industry in the policy and strategy documents and reports, it is perhaps surprising that the recommendations give barely any attention to the primary agents of change in the construction industry - i.e. organisations, and the centre-point of construction activities that can trigger wide scale changes - i.e. projects (cf. Green, 2019). An understanding of how micro-developments at firm and project levels (i.e., the industry niche) can be amalgamated for change is crucial, from a policy perspective, if an industry-wide uptake of OSM is to be realised and the targets for a 'revolutionised' construction sector in 2025 are to be fully or partially met.

In the extant literature, many studies and reports cite OSM as the 'future' of innovative construction project delivery and the starting point for a transformed industry that delivers high quality products, is more efficient, highly productive and safer (e.g. Goodier and Gibb, 2007; Ågren and Wing, 2014; Abanda *et al.,* 2017; BCG, 2019; House of Lords, 2018). Despite the plethora of studies motivated by its 'transformative power' if adopted at scale, critical views examining the multi- layered and -faceted modifications necessary for a wide scale uptake of OSM are scarce. Missing from policy debates is an understanding of the how micro-level developments involving the primary agents of industry change (i.e., organisations) and their use of OSM for project delivery could be aggregated to create critical momentum for change.

The Multi-Level Sociotechnical Transitions Perspective

The multi-level sociotechnical transitions (MLS) theoretical framework was developed primarily by Geels (2002; 2005) and colleagues (Geels and Kemp, 2007). It is a network approach for explaining how changes (i.e. technological transitions) in the way sociotechnical (ST) functions (e.g. construction, healthcare and transportation) occur across three levels: landscapes, regimes and niches. The different levels, according to Geels (2002, p.1259), 'are not ontological descriptions of reality, but analytical and heuristic concepts to understand the complex dynamics of sociotechnical change'. The MLS view provides the needed lens to explore how a dominant stable innovation can emerge and trigger niche cumulation, while helping identify the non-technical aspects of an established regime that would have to co-evolve to make a multi-level technological transition a reality.

According to Geels (2002), landscapes are the overarching socio-material contexts of firmly established structures that govern overall sets of multifaceted sociotechnical interactions that may occur in a place. The metaphor of a 'landscape' highlights, on one hand, the rigidity of the deeply rooted structures and practices that guide societies and, on another hand, helps to convey the multiplicity of interconnected factors it comprises. The heterogeneous composition of ST landscapes includes material and spatial layouts of buildings and cities, oil prices, geo-political climates, socio-cultural values, collective concerns and economic circumstances. A landscape therefore comprises broader, non technology-specific factors that are external to, but influential on, what happens in regimes and niches. Changes to landscapes do occur, albeit very slowly. ST regimes, embedded in landscapes, refer to semi-coherent rules and established practices that prescribe norms, orient and guide activities of actors, and provide stability to sociotechnical configurations in an industry. In the MLS heuristic, regimes are made up of technology, user practices and markets, meanings, infrastructure, industry structures, policy and technological knowledge. These factors are in a continuous process of co-development in order to maintain stability or adjust to changes in an existing regime (Geels, 2002; 2005). An existing regime may evolve in response to landscape pressures, creating opportunities for a niche-level breakthrough to re-configure established structures. Within the MLS framework, niches are crucial because they form the nucleus of technological transformations and trigger 'radical change' in established regimes. In niches, various actors seeking to bring innovations to established methods in an industry typically embark on unconnected attempts, developing their own discrete innovations. The emergence of a more stable technological innovation at the niche level holds the potential to coalesce other technological developments into a dominant design - creating a niche cumulation (Geels, 2005). Through well-coordinated efforts by dominant actors, niche level amalgamation could be aligned with regime developments to trigger a reconfiguration through co-evolution and realignment of actor patterns to begin a technological transformation (Geels, 2002). Geels and Kemp (2007) exemplify the preceding in their analysis of how sewer systems evolved from cesspools to integrated systems, and how waste management transitioned from landfilling to differentiated waste handling with energy re-use in the Netherlands.

Interactions across the three levels can be understood as nested, with niches embedded in ST regimes, which are in turn subsumed in landscapes. Developments in the landscape (e.g. changes in geopolitical climate, labour migration, increase in housing shortage and homelessness) can, therefore, exert pressures on existing regimes, building up tensions that may create windows of opportunity for new technologies (Geels, 2005). Whilst a macro-level landscape comprises "slow changing external factors, providing gradients for the trajectories", the meso-level ST regime "accounts for stability of existing technological development and the occurrence of trajectories" and micro-level niches create the context for "radical innovations" (Geels, 2002, p.1261). It follows from the foregoing that attaining largescale scale technological transformation entails, first of all, complex adjustments to wide-reaching factors. Secondly, it requires attention to niche level developments and their alignment with changes in ST regimes to trigger incremental regime-level changes.

RESEARCH METHOD

This research is based on a review of 31 secondary data sources using constructs from the MLS theoretical framework in order to identify macro, meso and micro developments related to OSM and construction industry transformation in the UK. The documents reviewed comprise five government construction and industrial strategies, nine publications by government departments and arms-length bodies, eight industry reports and nine relevant media publications. Three key questions underpin the study's analytical framework: 1) What are the macro, meso and micro developments related to the take up of OSM? 2) How can the ongoing developments be understood in the context of industry transformation attempts? 3) What central development holds the potential to drive an industry-wide uptake of OSM? The concepts of 'landscape', 'sociotechnical regime' and 'niche' developments were used in coding the data in NVivo 12.0 and the developments identified around OSM adoption were consequently synthesized. Examining the different documents helps put forward a conceptualization of how construction industry transformation entails multi-dimensional sociotechnical developments that need to be understood if the goals envisioned in the government's reform documents will be achieved in part or fully.

Construction Industry Transformation: A Multi-Level Sociotechnical View of Developments

Landscape and Regime Level Developments

Government economic policies (e.g. austerity measures), geopolitical developments like Brexit, a national problem like increasing homelessness, low housing supply, a global challenge such as climate change and increasing infrastructure needs for a growing population are among the landscape factors that are impacting the construction industry and pushing the need for changes in how projects are delivered. Delivering better quality buildings faster and cheaper, at scale and in ways that offer more budget and time predictability, have consequently become priority areas for the government - the single largest client of the construction industry (IPA, 2019). The wide-ranging landscape factors have built up pressure, with calls for more innovation in how the construction industry is organised and projects are delivered (e.g. Farmer, 2016).

Overarching structures, rules of practice and established norms among actors (e.g. clients, contractors, consultants, planning authorities, technology vendors) that presently govern the construction industry are deeply embedded in configurations that are not oriented to allow a widespread adoption of OSM (Farmer, 2016). Despite pressure from the landscape yielding some (miniscule) changes in the existing sociotechnical regime of the construction industry, a lot remain unchanged (KPMG, 2016). Procurement routes for the majority of projects continue to promote adversarial relations, supplier networks are developed based on broken-down work packages where the lowest bid wins and processes of construction remain heavily labour-intensive and in-situ (House of Lords, 2018). Construction sector policies advocating the uptake of OSM also lack clear pipelines of infrastructure demand and incentivising messages (Green, 2019), and lending facilities are more aligned with projects which use 'tried and tested' conventional building techniques (House of Lords, 2018). Planning requirements, regulations and materials standards, labour skills and training, and the use of novel or borrowed technologies have all evolved and are 'locked-in' to the established sociotechnical regime. Exceptions include recent policy documents (e.g. HM Government, 2018; IPA, 2019), which are intended to transform the UK construction industry. The reform agenda set out in these documents are indicative of the government's readiness to nudge the construction industry to increase the adoption and use of OSM. With well-coordinated effort from a significant actor like the government and relevant industry stakeholders, the existing sociotechnical regime - which is not well aligned to encourage a widescale adoption of OSM - could be acted upon to create a 'window of opportunity', allowing niche level developments to breakthrough.

Niche Level Developments

As earlier noted, the use of OSM for construction project delivery is not new. For over three decades, projects have incorporated elements that are manufactured in factories and installed in a final location on site (NHBC, 2019). It is therefore unsurprising that 'sub-assemblies' and 'manufactured components' are the most common forms of OSM reportedly used by around 75% of clients and contractors on their housing projects in the UK (NHBC, 2016). It follows therefore, that technologies supporting the deployment of OSM do exist and have been used, albeit in limited ways when compared to on-site construction techniques. Growing awareness of the potential benefits of OSM by government and private clients has contributed - in part - to the formation of joint ventures, the establishment of dedicated departments/units in construction organisations, the expansion and setting up of manufacturing plants, and the creation of technological solutions in the form of platforms enabled by computer-based digital technologies for design, manufacturability and error checks, costing, fabrication and quality checks. Unlike earlier applications of OSM several decades ago (cf. NHBC, 2019), increased computing power over the past two decades has enabled the use of digital technologies hosted in software packages such as Bentley, Revit and ArchiCAD for the manufacture of components and the deployment of OSM (Abanda *et al.,* 2017). Some private UK firms (e.g. Bryden Wood, ilke Homes, Urban Splash and TopHat) and some government ministries and departments are already exploring the use of some of these digital technologies with OSM for their projects (IPA, 2019; Offsite Hub, 2019).

Current 'top-down' government initiatives to create a demand push for the widescale use of OSM include the commissioning of a £253m 1,680 capacity resettlement prison by the Ministry of Justice; the Department for Business Innovation and Skills giving a £22.1m grant to Laing O'Rourke for the development of offsite manufacturing solutions; and a £38m joint housing scheme between Homes England, local authorities and private developers across the country. 'Bottom-up' attempts by industry actors include a £75m investment by Goldman Sachs in the use of OSM for housing provision, contractors establishing manufacturing factories and the formation of joint ventures (e.g. Laing O'Rourke, Legal and General and Touchstone) (Offsite Hub, 2019). These examples highlight some of the discrete niche level developments related to the adoption and use of OSM.

The multiple efforts are limited in terms of their ability to cause significant shifts along construction supply chains. As typical of niches, various actors have embarked on different attempts, developing their own innovations. The discrete nature of the initiatives is attended by the problem of interoperability as the technologies underpinning the OSM solutions are often bespoke and firm specific, severely impeding wider uptake attempts (House of Lords, 2018). Although such manufacturing technologies serve organisational commercial interests, they narrow chances for wider uptake and sustain the multidirectional nature of niche level developments. In the absence of a stabilised dominant design, the potential for a 'radical' transformation of the current construction industry might not be realised. This risk brings forward the need for a 'strong' landscape and regime actor like the government to methodically establish and stabilise dominant innovations that could break through to the regime level and trigger wider changes to help fulfil the reform agenda.

Towards a Breakthrough: The Platform Approach

The UK government has initiated steps to roll out a platform approach to design and manufacture for assembly (P-DfMA). Both DfMA and OSM share the principle of component-based design and construction of built assets (Abanda *et al.,* 2017; Goodier and Gibb, 2007). The platform is suitable for 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). Thus, despite being called a platform for 'DfMA', its underlying principles align with the arguments put forward for OSM in this paper.

According to the IPA (2019, p.5), the platform approach "was selected for a number of reasons... to follow and accelerate what is currently the most promising trend in the construction engineering sector". The platform will be initially adopted by five government departments (Education, Health and Social Care, and Transport) and ministries (Justice and Defence) as part of a move to create a client-demand push for the use of OSM for project delivery. It is the government's position that "adopting digital and manufacturing techniques wherever appropriate in government-led building projects will help drive better performance in the construction sector..." (IPA, 2019, p.1). With public sector procurement accounting for over 51% of the value of UK construction work (ONS, 2019), the government is using its position as a dominant client to push suppliers in the industry towards its desired transformation goals. The platform approach, therefore, represents the single most recognisable development that holds the potential to lead to any 'real' step changes towards an industry-wide adoption of OSM.

The platform is underpinned by the three principles of 'design for manufacture', 'platform centredness' and being 'open for manufacture, use and procurement' (IPA, 2019). Designing for manufacture presents a shift away from design for on-site construction - which prevails in the existing preferred practices of the industry - and focuses on component-based project delivery. Unlike conventional approaches to design, the underlying principle emphasizes standardisation and interoperability of digitally designed components to be used in procurement and the construction of built assets. The components designed should be easily manufactured, scalable, and used repeatedly across projects. The skills requirement for a shift towards this 'manufacturing-led' design holds implications for the future of technologies used for design and the professional services offered in this area. Using a platform approach means that the components designed should be usable across different kinds of built assets, without limitations on their use in different project schemes. By ensuring that components comply with quality standards and are interoperable, the government anticipates enabling the creation of a new market for entrants to exploit. Enforcing interoperability implies changes in manufacturing platforms and configurations to suit the production of standardised components.

As with other technological innovations (cf. Orstavik, 2014), the new markets that would emerge around this platform approach would consequently impact the technologies used, and the supplier networks needed, by clients and contractors for projects. To be open for manufacture, use and procurement means that anyone should have the opportunity to make, use and buy components for legitimate purposes. Furthermore, it suggests a multi-party access to the design and use of the components for different projects, requiring components to follow outlined parameters for interoperability. This principle comes with a significant shift away from bespoke designs for projects and may change how clients request the services of design professionals. The identity of the latter may be challenged as access to interoperable components becomes more open for multiple industry actors. A multiparty access to the design and use of components would change existing procurement routes, risk allocation, and common forms of contract in the existing regime where clients are risk averse and contractors have to, in essence, charge a fee to take on the risk as part of delivering a project (cf. Green, 2019).

In summary, the platform approach is designed to change the processes of planning, design, procurement, construction and management of built assets. It represents an attempt by the government to: streamline public sector procurement for buildings for which there is value for money in using OSM; create and sustain a market for innovations around the approach for projects owned or procured by the five government departments and ministries, their arm's length bodies and devolved authorities; and (re-)focus innovative developments related to OSM and digital technologies in the UK construction sector around a single platform to ensure incremental developments. Here, the government, as a strong / dominant actor, can be seen as accelerating the creation of niche cumulation whilst repositioning policy at the regime level to favour a breakthrough. With recent policy serving as a backbone for the implementation of the platform approach, and with the reform agenda at its forefront, the implementation of the platform holds the potential to trigger changes in the existing sociotechnical regime.

CONCLUDING REMARKS

This paper reviewed and discussed recent multi-layered developments related to the UK's construction industry reform agenda with a focus on OSM. The current trajectory of developments has limited potential to create any significant step changes that would lead to industry transformation. It consequently highlighted the potential of the government's platform approach to be a central innovation that could create the much-needed momentum to trigger 'real' changes towards the realisation of industry reform goals. Through the lens of the MLS theoretical framework, this development can propel a breakthrough from niche to regime levels. However, it is not expected that the platform approach would completely dominate the existing regime after the breakthrough. An industry-wide embrace would follow the pathways of complementary use, co-existence and finally competition with prevailing construction techniques until actors begin shifting their collective practices across the industry.

While the platform holds some potential in triggering changes, we do not claim it is the sole development to drive a widescale uptake of OSM. Beyond this 'top-down' techno-centric solution, achieving the desired industry transformation requires a co-evolution of the platform with policy, construction market dynamics, actor practices and existing technologies used for project delivery. How these co-developments will occur provides one direction for future research. It is expected that actors benefitting from the existing regime will resist changes. However, the government, as a strong actor, has the resources and influence to implement policies that could lessen resistance across the industry, facilitate co-evolution and help revise actor patterns in order to sustain incremental developments towards the envisaged transformation. Another direction for future research could explore coercive or incentivising OSM-related policies and consequent industry responses in tracking developments towards a reconfiguration of the existing ST regime as part of the transformation agenda.

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