EXPLORING PROCESS, PRODUCTIVITY AND STRUCTURE IN DESIGN

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It is increasingly difficult to benchmark performance and record, manage and transfer information effectively. Modern construction projects are complex and the roles and responsibilities of designers are inconsistent. This raises concerns about rework and inefficiencies in construction projects. To address these concerns is an opportunity to improve project performance and profit margins. Increasing calls for innovation, growing client involvement and input from a range of stakeholders have led to the creation of complex project management structures. This has added to the centrality of the design process, underlining the need to understand and assess the design process and its productivity. The research forms part of a project intended to investigate the productivity of designers and engineers, with the aim of enhancing design process productivity. An improved understanding of design processes and identification of the factors that may contribute to design productivity within a design-led organisation is intended to help improve the management of design activities. As part of an ongoing PhD project, the aim is to present a critical review of literature in order to understand the complexity of design and to explore the roles of effective management, organizational structures and emerging tools in the potential success of design. The literature reveals that the design process and interactions with stakeholders increasingly requires operational and managerial complexity. The relationships between technical, operational and managerial complexity requires a better understanding of what design actually is, why it is complex and how this impacts project organizational structure. It would be useful to focus the next stage of the research on the effectiveness of the design process, than its efficiency.

Keywords: design complexity, design process, organizational structure, productivity.

INTRODUCTION

Modern construction projects are complex and the roles and responsibilities of designers are inconsistent. It is becoming increasingly difficult to benchmark performance and record, manage and transfer information and knowledge effectively (Zhao *et al.* 2007). This adds to concerns regarding inefficiencies in construction projects. An improved understanding of design processes and identification of the factors that contribute to design productivity within a design-led organisation will help

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improve the effectiveness and efficiency of design activities and quality for the lifetime benefit of all users.

Demand for innovation, growing client involvement and input from a growing number of internal and external stakeholders has led to the creation of a complex project structure for management (Hughes and Murdoch 2001). This has also added to the central importance of the design process, underlining the need to understand and assess the design process and its productivity in a scenario where 'design is constituted both by designers and by non-designers through their consumption of and engagement with the outcomes of designing' (Kimbell 2009: 3). Examining the construction design process to understand and assess its productivity needs an understanding of the construction context, and of the complexity of the design process and the associated challenges. The aim of this paper is to explore and review the literature on this topic in order to form a context for future research.

BACKGROUND

Organizations are becoming increasingly dependent on the productivity of their knowledge workers (KWs) (Ramírez and Nembhard 2004). The manual aspects of production have largely been automated and so it is the KW which gains organizations the edge in their markets. Like all industries, production in the construction industry has been moving towards knowledge-driven processes while manual work has become increasingly automated. Drucker (1988) explained this as an outcome of a broader shift from industrial to post-industrial age. This shift underpins the changing ratio of manual workers to KWs from 2:1 in 1920 to 1:2 in 1980 (Davenport 2002), with the result that the KWs are emerging as the single largest group in the workforce of any developed country (Drucker 1988). This requires increasing these KWs' performance and productivity by involving them in the research and research-informed organisational strategic plans if companies wish to make substantial gains.

Organizations across all fields of production are faced with the challenge of recovering the rising costs of materials, labour and other production expenses, as well as the challenge of creating opportunities to increase profits for future growth, development and sustainability. Some potential options include raising product prices to meet the increasing costs, cutting production costs, and improving the production process to make it more cost-effective. However, all these strategies have relative value in the local and global industry contexts where 'hard to measure' KW is replacing 'measurable' manual work (MW). The measurable nature of MW made it possible to develop frameworks or approaches for evaluating its productivity, which underpinned improvement of related processes and practices. Ramírez and Nembhard (2004: 603) argue that 'Measuring manual worker productivity was a critical step in laying the groundwork for improvement efforts in the manufacturing sector during the first half of the twentieth century'. Recognising the importance of KW in productivity, the focus of research has to shift to KW which needs to be explored for quality, efficiency and output among other things.

Design work in construction is commonly defined as complex and creative, aligning with KW. In addition to the complexity of the design work itself, the nature of this work is also becoming highly competitive and demanding. Calls for cost-cutting while a reduced construction demand in some previously high-demand-areas such as the Middle East has meant a decrease in work for many international companies; the previous momentum of demand for workforce has reduced. The emphasis is no longer on bringing more people in, but on using the work force, which has increasing number

of KWs, more efficiently and strategically. Organizations are trying to use expertise and resources based at different sites effectively for global work, reinforcing the significance of communication, new technologies, and strategic deployment which require use of advanced technology and improved management. Physical transfers or relocations of the knowledge/expertise resources spread at different international bases, in response to demands at different locations/countries can be expensive. The current scenario necessitates an informed development and deployment of sustainable strategies, frameworks, and processes for managing a range of resources, which has added to the centrality of design and design-related applications in the construction industry.

DESIGN AND DESIGN PRODUCTIVITY

Examining the design process and its productivity requires an understanding of the concept in the context of construction, its drivers, and the nature of the product. The 'term design has different meanings to different researchers' (Love 2000: 296). Conway (1963: 260) offers various interpretations of design and designers and argues that 'Different people, even engineers, do not ascribe the same meaning to the word Design, or function to a Designer' (p.260). These range from design as a rational activity to design as an art or design as a creative activity. Generally, it is used both as a noun and a verb. As a noun it is understood as a concept or a product; for example, a plan or drawing that is produced to show the look and function or workings of a building or any other object before it is made. It is the art or action of conceiving of and producing a plan or drawing of something before it is made, presenting the purpose or planning that exists behind an action, fact, or object. A good design can help its reader understand complicated information through a clear presentation that can be an end product in itself. However, design as a verb is an ongoing activity, a process or procedure, where the design itself is in a constant process of development. The BS 7000-10 (2008) defines design as generation of 'information by which a product can become a reality'. This vagueness of the definition is suggestive of the complexity, and multiple dynamics of the design process, underlining the need for research to improve its understanding.

Gray and Hughes (2001: 24) describe design as 'a creative and very personal activity The architect takes the client's brief and uses design skills to develop a three-dimensional interpretation which other designers use as a basis for their own work'. This definition points to two elements of design – creativity to realize the design, and the translation of that realisation into delivering an output to meet the needs/requirements. Potter (2002: 10)defines design as the product of 'a plan conceived in the mind; not only as a set of drawings or instructions, but as the ultimate outcome from manufacture'.Walsh (1996: 513) claims that all design terms 'involve the creative visualisation of concepts, plans and ideas; and the representation of those ideas (as sketches, blueprints, models or prototypes) so as to provide the instructions for making something that did not exist before, or not in quite that form'. Similarly, Khandani (2005: 4) explains that 'Engineering is the creative process of turning abstract ideas into physical representations This creative act is called design'(2005). The construction design process is a specialized and highly demanding form of problem solving (Lawson 1997). It is widely claimed to be the key project process (Cockshaw 2001). According to Cross (2006) designers are solution focussed and their mode of thinking is constructive or generative. Gray and Hughes (2001: 24) argued that in spite of design process being a very personal creative activity, the whole project's design becomes a combination of the motivation and expressions from

many individuals and is 'viewed by the separate members of the team from many different directions and, in particular, with regards to how well it will accommodate their own needs and wishes'. Due to the complexity of design work, many designers with specific expertise are involved in the construction design process. Tribelsky and Sacks (2011: 85) rightly claim that in the current construction contexts managing 'smooth and continual flow of information among teams of independent designers is one of the central difficulties in detailed design of complex civil engineering projects'. They recommend high quality design documents and flow of information to achieve the performance targets. Another significant point to note here is the potential challenges of 'complex project structure for management', underlined by Gray and Hughes and Murdoch (2001), as mentioned above.

Design has been the basis of construction industry irrespective of the nature or details of the design. Bibby (2003: 1) explains it as 'a dynamic and complex multidisciplinary process, involving many parties and performed in a series of iterative steps to conceive, describe and justify increasingly detailed solutions to meet stakeholder needs'. From earlier sketchy outlines and drawings to more detailed architectural blue prints and now highly elaborate digitized multi-dimensional designs is a process reflecting increasing emphasis on the significance of design in the construction industry, and a widening of the aspects of related activities to be considered in the design. This has extended the work and responsibilities as well as influence of the designers, requiring greater communication and higher collaboration among different actors and stakeholders for achieving desired outcomes which are cost-effective and efficient. Kimbell (2009: 9)argues that 'taking the plural noun form of "design" which can mean the outputs created during a process of designing, such as blueprints, models, specifications and what is finally assembled in products and services, the term designs-in-practice draws attention to the impossibility of there being a singular design'.

Kimbell (2009) discusses and explains two dimensions of design as design-as-practice and designs-in-practice. She argues that 'design-as-practice mobilizes a way of thinking about the work of designing that acknowledges that design practices are habitual, possibly rule governed, often shared, routinized, conscious or unconscious, and that they are embodied and situated' (p.9), while the concept of 'designs-in-practice … acknowledges the emergent nature of design outcomes as they are enacted in practice' (p.9). The design embodiments such as visual artefacts are certainly a part of the design process and KW, and as (Whyte *et al.* 2008) evidenced 'visual artefacts which constitute part of the practices of designers and others, play important roles in knowledge work' (quoted in Kimbell 2009: 9). However, Kimbell (2009: 10) continues to argue that:

'The idea of designs-in-practice foregrounds the incomplete nature of the process and outcomes of designing (Garud, Jain and Tuertscher 2008). When the designers have finished their work and the engineers and manufacturers have finished theirs, and the marketers and retailers have finished theirs, and the customer or end user has taken or engaged with a product or service artefact, the work of design is still not over. Through their engagement with a product or service, the user or stakeholder continues to be involved in constituting what the design is.'

The idea of designs-in-practice emphasizes the incomplete nature of the process (Garud, Jain and Tuertscher 2008). Designers need to be flexible, spontaneous, and creative to accommodate the demands of different stakeholders. An important aspect

of design is that although it is prepared by designers, the 'non-designers' (Kimbell 2009) need to understand it as they will be involved in giving life to the design. Design is the converging point where various skills and disciplines link together in a process where 'a product can become a reality' (British Standards Institution 2008). A better understanding of design and design processes would therefore, allow a reduction in time, re-working, and cost and therefore optimisation of designs for the lifetime benefit of all the users (Raisbeck and Tang 2009).

Design guides, controls, and determines the project work. The growing emphasis on design research and centrality of design reflects the need to develop solutions that can be used 'in various organizational contexts to achieve specific objectives' (Vahidov 2006). Development of design from basic drawings to the advanced design software such as CAD and Building Information Modelling (BIM) reflects responsiveness to emerging needs for enhancing design productivity. A good design is not just sound and strong construction but it also necessitates giving full considerations to all its complex dimensions. This raises questions such as: what is the required information for design process? Who is involved in the process? Who is the information generated for? How is the information generated?

The discussion above indicates that the input required for the design process comprises of multifaceted information, knowledge and expertise. Those involved in the process include various direct and indirect contributors, and the information generated is for interactive use across all those involved in the design process over its extended life span. This non-linear multifaceted nature of input requires specialist knowledge, complex tools for information generation and informed project management. The increased technical complexity of design has led to increased operational and managerial complexity. Organizational structure and the structure of design teams directly relate to the operation and management of design and its efficiency and effectiveness. Drucker (1977) explained that efficiency is doing things right and effectiveness is doing the right thing, and the two complement each other for organisational performance.

TECHNICAL COMPLEXITY OF DESIGN AND DESIGN TOOLS

The increased technical complexity of design has led from basic drawings to highly advanced design software. The introduction of Computer Aided Design (CAD) which presented a huge shift from manual drafts, saving time and cost, and facilitating improved collaboration, document distribution, and data management. CAD has been appreciated 'for accelerating the production of drawings and documentation, for supporting the exchange of design information among groups using the same CAD systems and for providing visualization tools', but with some critique that CAD users often 'are solving computer problems about how to draw, not architectural problems' (Cad for Principals, online). Other critique included its costs in terms of training and equipment and an isolated activity that did not support a communicative team environment. However, project profiles from a relevant organisation (Halcrow, online) acknowledge CAD as providing opportunity to all stakeholders including the engineers and the CAD team to 'work together in a more integrated and efficient way, sharing drawings between themselves, external team members and the client' (Halcrow, online). CAD is perceived as a quicker and more efficient way to share drawings and facilitates closer collaboration through online communication and review of drafts. Technically CAD offers improved design presentations by providing 2D and more recently 3D visual representation of design information. Better

presentation and representation of information has helped for instance to reduce design errors and contributes to increased efficiency and productivity in construction.

Another significant technical development in this field is Building Information Modelling (BIM) with associated technologies and processes. American Institute of Architects (2008) defines BIM as the digital representation of the physical and functional characteristics of a project. It is a platform which integrates information about a project from design through construction and into operations and facilities management. This 3D technology has the potential to create more precise visualisations, giving accurate information regarding the cost, appearance and performance of a project. As multiple dimensions of design are made visible with all associated details, co-ordination, quality and efficiency are increased, and delays, risk, environmental damage, and waste are reduced. BIM users emphasize that BIM is not a mere improvement on CAD but a new solution to construction challenges, as explained by Richard Waterhouse Chief Executive, RIBA Enterprises (National Building Specification 2011).

BIM appears to respond well to increasingly complex demands in the construction industry today. It 'facilitates complex processes and analyses that were previously too laborious or complex to perform' (Autodesk 2005: 1). It is argued that 'BIM could help improve the quality and speed of project related decision making; manage supply chains; sequence workflow; improve data accuracy; reduce time spent on data entry; reduce design and engineering conflicts and subsequent rework; and improve lifecycle management of buildings and infrastructure'(Mcgraw-Hill 2009). It is not just switching software but a culture and organisational change, requiring high level collaboration and responsibility, highlighting the operational and managerial complexity of the design activities. The users need to be more efficient and proficient. In a UK survey National Building Specification (2011: 14) found that 'BIM brings better co-ordination of construction documents (81 per cent agree), improves productivity, (84 per cent), increases delivery speed (51 per cent) and improves visualisation (85 per cent)'; but it also highlighted that nearly 90 per cent of people will need to change their workflow practices and procedures.

There are clear signals of the increasing use of advanced applications such as BIM in the construction industry, particularly for large projects. It can be argued that BIM as a design-centric technology, with emphasis on sharing and collaboration, can be the answer to multiple challenges in the construction sector. However, it needs to be recognized that all these processes and applications work in an organisational context and are influenced by organisational structure, functions and activities requiring informed project management and leadership skills and expertise.

ORGANIZATIONAL STRUCTURES

As discussed above, design increasingly becoming technically complex. To address this technical complexity engineers and designers are needed to become specialized in specific aspects of the design. One consequence of this growing emphasis on specialisations is that the designers/engineers with their specialism fields may become less involved with other aspects of design work, thus being responsible primarily for a certain "fragment" of the design. In addition to that, inter-organizational and contractual relationships further isolate the experts, and complicate the work relationships across these individual "disciplines" or specialized designers underpinned by a lack of clarity regarding their actual and contractual responsibilities and their obligations to one and another. A complex managerial task emerging at the

organizational level is to integrate and co-ordinate these 'specialists' from multi-disciplinary teams in such a way that the 'team members strive to contribute beyond their disciplines' traditional boundaries' (Busseri and Palmer 2000: 224)

People involved in design process are nodes in design processes where one person output can be input for another person, making it a complex system that needs to be investigated and understood. 'Complexity scientists' contend that unpredictable behaviours and new laws arise as more complex systems emerge, which is the reason those systems must be studied at the levels of their emergence' (Davis and Sumara 2005: 455).Furthermore, they argue that although 'complex phenomena represent interactions of events, activities, and practices that coalesce in ways that are unpredictable but nonetheless highly patterned' (p.161). Searching for patterns among unpredictable phenomenon can contribute to structural and systemic efficiency and effectiveness, leading to improved project management.

Senge (1990: 43) argued that complex systems exhibit networked rather than hierarchical structures. They have multiple branches extending in many directions rather than vertical lines of control. Senge advises to 'look into the underlying structures that shape individual actions and create the conditions where types of events become likely'. Bergstrand (2009), drawing on Burrell and Morgan's (1979) framework for categorising sociological paradigms presents a model relevant for KW productivity management systems in business contexts, labelling the four quadrants as Envision, Design, Build, and Operate. Bergstrand posits that 'Within the design process these four units can be seen as parts of whole, requiring complex mental models to define the work and correspondingly complex structures and processes to productively manage the work (p. 89). A complex phenomenon demands paying informed attention to all situated aspects. Complexity drivers are multiple and 'complexity-aware approaches ensure that change is linked into the natural complexity of local environment' (Beautement and Broenner 2011: 26). 'A complexity approach [in an organisational context] would suggest that encouraging and empowering people to make small changes in their own spheres of influence and activity can be a highly effective way of transforming an organisation' (Mcmillan 2004: 86).

Structures underpin activities and processes and 'the system causes its own behaviour' ((Meadows 1982) quoted in Senge 1990: 43). People develop their behaviour, activities, and responses in the context of organisational structure and system/s. '"Systemic structure" is concerned with the key interrelationships that influence behaviour over time' (Senge 1990: 44). To survive in a competitive field and to continuously transform itself, an organisation needs to enhance its capacity to learn and innovate as a structure and also to facilitate the learning and development of its members. Archambault (1974)was one of the most well-known advocates of hands on learning who emphasized learning through interaction, experience and reflection. Reflection on practice was theorized as reflective practice by Schon who explained it as organisational learning. (Schön 1983)emphasized the value and contributions of organisational learning and reflective thinking, maintaining that organizations and individuals should be able to incorporate lessons learned throughout their lifespans. However, developing learning organisations also has challenges in the context of complex organisations as this signals on-going learning. This learning is both for the individual and the organisation. Admittedly, 'organisations and individuals are complex adaptive systems and therefore have the ability to transform themselves in order to adapt to changing' (Mcmillan 2004: 102).Nevertheless, when the two are not learning simultaneously and interactively, they lose their capacity to develop.

A learning organisation is different from the traditional concept of organisation with linear structures and lines of command, therefore they demand a new view of leadership. (Senge 1990: 342) conceptualizes leaders as designers and argues that 'the essence of design is seeing how the parts fit together to perform as a whole'. In this learning organisation 'the leaders' task is designing the learning processes whereby people throughout the organisation can deal productively with the critical issues they face, and develop their mastery in the learning disciplines' (p.345). Senge (1990: 69) suggests "systems thinking" 'for seeing the "structures" that underlie complex situations'. Senge (1990: 12) presents systems thinking as the fifth discipline 'that integrates the disciplines, fusing them into a coherent body of theory and practice'. The other four disciplines are Vision, Mental Model, Personal Mastery and Team Learning. According toSenge (1990: 7), systems thinking is 'a conceptual framework, a body of knowledge and tools that has been developed over the past fifty years, to make the full patterns clearer, and to help us see how to change them effectively'. The five disciplines jointly make the organisation into a 'learning organisation'. If an organization fails to embrace all the necessary aspects, problems can obstruct the process of learning and development. Senge emphasizes that a learning organisation 'is continually expanding its capacity to create its future … [through] generative learning' (p.14). Senge underlines the significance of systems and structures and claims that "more often than we realize, systems cause their own crises, not external forces or individuals' mistakes" (p.40). Therefore, emphasizing the need to see and detect those 'gradual processes that often pose the greatest threats' (p.24) because we do not take notice of them while they are gradually weakening the systems or slowing the progress. Design is also a complex process with the risk of many activities going undetected that could negatively impact on design productivity. Systems thinking can be a relevant tool for analysing design productivity because it is a problem solving approach and a framework for understanding how things influence one another within a whole. In organizations, systems consist of people, structures, processes and technologies that work together towards a whole. While the whole is in the process of becoming, some or many interdependent parts may display choice and/or behave independently, posing challenges that slow the progress. Today's complex organisations and systems are made up of diverse sub-units that perform specialized functions. 'Systems thinking' focuses on understanding of a system by examining the linkages and interactions between the elements that compose the entirety of the system to eliminate or control such possibilities.

The complexity and uncertainty of the construction design process requires the application of significant management efforts for project success (Bibby 2003, Gray and Hughes 2001). The nature of the work involved in the design process which tends to be invisible and creative heightens the challenges. The difference between KW and manual work is that manual work can be automated while KWs (engineers/designers) need to make professional judgements that are subjective, and such judgements can have a huge impact on the final product. Misha Black, (1969) the British architect and designer described the "profession" of design as 'the offering to the public of a specialized skill, depending largely upon judgement, in which both the experience and established knowledge are of equal weight, while the person possessing the skill is bound by an ethical code and may be accounted by law for a proper degree of skill in exercising this judgment' (quoted in (Potter 2002: 15)). Focusing on the product of design, avoiding exploration of possibilities, carries the risk of creating a generation of engineers shy of making professional judgements, and relying heavily on

standardization. This is particularly counterproductive when considering the need for innovation to beat the competition in a very strong industry.

CONCLUSION

The design process generates and requires diverse information, knowledge and expertise. In addition, the design process is influenced by, and must cater for direct and indirect stakeholders of numerous disciplines and interests. This along with the specialist knowledge and increased technical complexity has led to increased operational and managerial complexity. The key role of tools such as BIM is not simply to increase technical capabilities, but rather the emphasis placed on sharing and collaboration. The impact of such tools on organisational structure, functions and activities merits further exploration.

The literature reviewed unveils the technical complexity of design, and operational and managerial complexity of design process, requiring exploring and debating how they impact on each another. This demands deeper consideration of what design actually is, what makes it complex and how this is linked to the organizational structure. It would be useful to focus the next stage of the research on the effectiveness of design in order to deliver long term benefits for all the stakeholders, rather than a short-term focus on making a particular aspect more efficient.

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