THE POTENTIAL OF BUILDING INFORMATION MODELLING (BIM) FOR PRECAST CONCRETE MANUFACTURING

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ABSTRACT

Precast concrete is increasingly used in the construction and the supply chain needs to work together to realise the benefits of the precast concrete. The challenges include the improvement of production processes, storage and delivery of the products to construction sites so that benefits of offsite production is efficiently achieved. The industry can benefit from the use of Building Information Modelling (BIM) provided major issues are addressed. A combined effort by manufacturers, researchers, and software vendors will be needed. Key areas for future research and development involve interoperability, compatibility, and standardization, as well as the development of new software tools to take advantage of the capacity that BIM frameworks already provide.

Keywords: BIM, precast concrete, modern methods of construction.

1 INTRODUCTION

Offsite production is increasingly used in the construction industry as a way of reducing waste, improving productivity and quality of the construction of buildings, civil and infrastructure projects. One of the key contributors to offsite production is the precast concrete industry with approximately £2 billion to the UK economy annually and employs more than 10,000 full time employment from more than 500 factory sites (Smith, 2013). The precast concrete reduces waste by about 50% due to factory controlled conditions of production as compare to in-situ concrete, eliminates the use of traditional on-site temporary supports and formwork and reduces construction time significantly (BRE, 2009). In addition to the general benefits of concrete such as fire resistance, thermal mass, sound insulation and durability, precast concrete provides specific benefits of construction such as speed, quality (reduced snags and errors), reduced need for plants on site, improved H&S and cost savings. Glass (2003) highlights that the barriers normally associated with precast concrete are inflexibility, appearance and service delivery issues.

The precast companies take up the specialist subcontractors role in the project delivery and require information from designers and contractors for efficient production and delivery of products to the construction sites. The precast concrete companies comprises of diverse group of people and involves very large range of products, materials and processes. The workforce is unskilled to semi-skilled which requires accurate instructions and details of the precast elements to achieve the quality and efficiency in production. The precast concrete units are generally very heavy requiring various loading, lifting and transporting equipment. Storage within the factory premises, retrieval, loading on the transport vehicles, management of delivery to the sites and unloading on site require careful planning and management. The aim of this paper is to evaluate and discuss through the literature review on how the industry can benefit from the use of Building Information Modelling (BIM), which has been a major government push in the construction industry to improve performance and collaboration within the project teams. A combined effort by manufacturers, researchers, and software vendors will be needed.

2 THE PRECAST CONCRETE INDUSTRY TODAY

The precast concrete represents about 28% of the market for cementitious products in the UK (BRE, 2009) and the industry is very diverse as it produces a large range of products using different manufacturing processes, and the companies involved vary from very small to very large companies. Glass (2003) referring to low rise housing identifies three broad categories of precast concrete uses: components, panels (2D construction) and volumetric (3D construction). The components market is well established in the construction and the other two which are regarded as modern methods of construction (MMC): panels and volumetric construction (also known as modular construction) are finding increasing use in the last two decades. The panels include floor and wall units integrated with services, doors and windows etc. The volumetric units include the concrete units with all internal and external finishes and services installed. There are broadly two different categories of precast concrete products used in the construction: made- to- stock standard products and made-to-order (also referred as engineered-to-order) bespoke structural products.

The made-to-stock products include standard building materials such as blocks, kerbs, lintels, slabs, bridge parapets etc. The moulds are used repetitively and highly automated processes are utilized. Both dry-cast and wet-cast concreting methods are used depending upon the type of products being produced. These products are used for gardening and landscaping as well as the structural elements for housing, commercial and retail developments. Key concerns for the production management of these products are stock holding, handling of the products, storage and retrieval and distribution.

Other category of products include made-to-order (also referred as engineered-to-order) structural components which are produced for bespoke sizes demanded by the construction project. The products comprise of flooring, roofing, claddings, foundations, frames and whole structural components. The elements are assembled on site to construct low-rise to high-rise buildings as well as large projects such as bridges or stadia. For these products, wet-cast method is used and the moulds are designed to have flexibility to be re-used again, thus requiring careful planning.

Bespoke concrete products require longer lead-time and complex production planning by the precast concrete companies to coordinate with the design and construction teams in a construction project. The precast concrete companies need to work closely with design and construction team to develop precast general arrangement drawings, which are used for production planning (Benjaoran *et al*. 2004). The delivery time requirement of the precast components is dictated by the actual construction programme on site. The delivery dates required for different components is different. The uncertainty on the construction programme impacts the precast concrete production, which may demand fast tracking of production or delayed deliveries specifically if the storage spaces are not available on site and Just-in-time (JIT) deliveries may be warranted. The production processes and the constraints of curing time required for the concrete products make it difficult to fast track the production.

The detailed design information may not be available to allow the lead time required to plan for the production and the bill of quantities needs to be accurate, which is not often the case as design keeps changing. A lot of time is spent by the precast designers on checking the design for errors, missing information and details. This will have impact on the production planning. The projects which have design build procurement will not have detailed information required as design is progressive with construction. To benefit from the economy of scale, as the precast concrete production requires bespoke formwork (mould), the mould is produced for largest piece and then adopted to other similar but smaller components. Lack of standardisation within the construction industry for precast concrete products means that the adoption of the moulds to cater for other components is less likely which will increase waste. Set up time for form work will therefore will be high. Frequently, the units produced have to be specially designed and made for a specific construction site; the complexity of the units varies considerably; the units have to be stored for some considerable time after manufacture before they are strong enough for use on the construction project.

3 PRECAST CONCRETE INDUSTRY PROCESSES AND BIM

New technological advances in materials, compaction and handling techniques are being used in the industry. The precast concrete industry has been in the forefront of innovation in terms of material behaviour such as self-compacting concrete, glass-fibre reinforced concrete, prestressed concrete etc to enhance the strength and behaviour of the concrete in different loading conditions. In the last two decades, there have been several initiatives internationally in improving processes and efficiency in the use of precast concrete products in construction.

Sacks *et al.* 2004 emphasise on the importance of the study of precast concrete production processes in order to explore the ways in which companies can explore their business and engineering could be realigned. Zhang et al. 2004, referring to Hycon project, highlight the significance of simulating the performance of concrete structures using virtual prototyping techniques and emphasises on standardisation and pre-assembly of components through the use of hybrid concrete. Marasini and Dawood (2002) use an integrated simulation approach to simulate stockyard layouts for precast concrete products by integrating production schedules, sales information, spatial information of the stockyard as well as a knowledgebase about product characteristics. Benjaoran et al (2004) provide the intelligent production planning for the bespoke precast concrete products. Precast Concrete Software Construction (PCSC) since 2001 is looking at ways of automate precast design and production processes by combining architectural, engineering, and precast concrete production designs together creating a 3D modelling. Recent developments include the development of Information Delivery Manual for Precast Concrete (LaNier *et al*. 2009) which is discussed later.

Principally the use of BIM would allow the designers and production managers to collaborate and do value engineering exercises to decide the precast solutions for the projects, minimise design and prefabrication errors. With the development of BIM, it can be expected that the processes of design, production planning, logistics planning would be more accurate and be easier to use by the supply chain for realising the benefits of precast concrete. Smith (2013) in the resource efficiency action plan (REAP) sets the industry targets for improving sustainability credential of the industry through the use of BIM and highlights a need for the sector to provide data in a BIM compliant form with complete resource efficiency and Environmental Product Declaration (EPD) data sets. The other aspects that it highlights that the use of BIM will enable better development of a bill of quantities, and thus more accurate pricing for projects.

4 THE BIM IMPERATIVE

4.1 An overview of BIM in the UK

The UK government has identified BIM adoption as a key requirement for the advancement and continuous competitiveness of the construction industry. The level of commitment is underlined by a particularly important Government mandate; starting from 2016 all public sector centrally procured construction projects must be delivered using BIM (HM Government, 2012). This followed from a 2011 report compiled by representatives from the construction industry, software vendors, and academia, that identified 4 BIM maturity levels (BIM Industry Working Group, 2011). In this categorization, Level 0 corresponds to the, still common, practice of employing unmanaged CAD models where collaboration is based largely on exchanges of paper. On the other hand, Level 3 is described vaguely as a “fully open process and data integration” based on “web services” with an allusion to concurrency. Understandably, this is not something that can effectively delivered by contemporary technology; instead, the target for most organizations is BIM Level 2. In this there are multiple, discipline-specific BIM tools, ideally in a 3D environment. The integration between these different models is left open to the user; the middleware, of vital importance for such an endeavour, is left open to proprietary systems.

As it is to be expected, there is a natural tie-in between BIM and modern methods of construction (MMC); though a clear agreed definition is yet to exist, it could be argued that effectively MMCs combine off-site manufacturing process, with a fully integrated BIM system. This however is hardly achievable; moreover, existing BIM technology is targeted towards traditional methods of construction which still constitute the vast majority of built works.

4.2 Current Approaches

Unsurprisingly, the importance attributed to BIM by government authorities has led to an exponential year-on-year increase in interest by practitioners, academia, and of course the (largely US-based) software vendors. The latter not only have had a major role in forming the policy from the beginning (BIM Industry Working Group, 2011), but also have invested heavily in getting the construction industry to adopt their products (Munsi, 2012). At university level there has been a rapid increase in interest in both teaching (integration of BIM in the curriculum, development of post-graduate taught courses etc), but also in research; BIM-related papers and projects have proliferated in recent years, while dedicated journals with a clear BIM focus have been set up (IJ3DIM, 2014).

Interestingly however, the approaches of researchers and the leading software vendors have diverged (Varoudis and Patlakas, 2014). The former are typically exploring different variations of systems, attempting to achieve what is promised as BIM Level 3. The latter, which understandably enjoy a privileged position both in terms of resources and interfacing with the industry, have moved towards a "master model" approach where all the different multi-disciplinary functions are contained within the same model in a single file of a specific file type, with limited compatibility and interoperability. The particular characteristics of the two approaches are summarized in Table 1.

Table 1: Characteristics of BIM approaches.

	Researchers	Software Vendors
system focus	any; emphasis on open-source, free, and text-based systems	in-house software suites
interoperability	major emphasis, with exploration of interfacing between different systems	moderate emphasis on in-house software; limited emphasis on third-party applications
version compatibility	little or no compatibility; projects tend to be "one-off"	moderate
platform stability and industry applicability	little or moderate; many projects do not aim for platform stability and immediate applicability	very high

5 IDENTIFICATION OF ISSUES FOR AN INTEGRATED BIM FRAMEWORK

As described above, there are numerous advantages in off-site production in general, and precast concrete in particular. Moreover, the potential of integrating BIM in the manufacturing process, and thus achieving a true MMC workflow, is particularly attractive. Thus, the question of why the majority of concrete structures are still based on on-site methods appears legitimate. The answer is twofold and lies firstly on the limitations of precast concrete already discussed, and secondly on the relative immaturity of BIM technology. The potential of BIM for precast concrete however is undeniable; as such, what is needed is an identification of the keys areas that emerging and future BIM technology should target, together with a recognition of the challenges.

5.1 Architectural Flexibility

As mentioned above, a main issue regarding offsite production methods is design flexibility. A major advantage precast concrete provides is the possibility to produce architecturally challenging forms in controlled factory conditions. However, profitability is partly based on the maximum reuse of the formwork. This often results in a limited offering of architectural forms in practice, with precast factories concentrating on offering cost-competitive standardized components. This effectively results in little flexibility in architectural design terms, an issue shared by all types of offsite construction.

BIM has the potential to increase the design flexibility by enabling manufacturers to share modelling and production formats with the client's architects and engineers. In addition, there is the capacity to produce formwork design tools within the BIM model; this should lower the costs of production of formwork, and potentially allow precast manufacturers compete better with onsite techniques.

It should be added however that current BIM technology is far from being able to compete with more advanced tools available for parametric design; concrete is the ideal material for the production of unusual forms as evidenced from landmark buildings designed with parametric tools such as Grasshopper. If precast concrete is to be fully competitive with traditional onsite methods, such functionality will need to be implemented in the same platform.

5.2 Engineering Transparency and Flexibility

An important issue with precast concrete has always been the limited engineering input engineers get in the process; typically the client's designers are provided with "black box" results, following from proprietary calculations by the in-house engineers. While for standardized construction this can be unimportant, or even simplify the process, it limits precast concrete's appeal for more atypical construction; effectively, it is a different type of design inflexibility. BIM has the potential to address this by enabling much better collaboration between manufacturers' and clients' engineers, and providing more efficient products. However, issues of Intellectual Property, model ownership, and object responsibility will be major challenges; this is similar to what is happening with BIM in traditional construction and there is certainly potential for the two industries to learn from each other.

5.3 Production Process

Production, transportation, and assembly are the key areas where precast concrete can both enjoy the greatest advantage over traditional methods, and face the greatest challenges. The precast industry has often been criticised of failure to adopt lean manufacturing methods and just-in-time production on par with the manufacturing industry (Low and Mok, 1999). As with design flexibility, in order for production and assembly to be effective, close collaboration is needed with the client's architects and engineers. In the US, the precast industry has clearly recognised this need, and an Information Delivery Manual (IDM) has been produced (LaNier *et al*. 2009). This is an important first step towards integrating the production process with the BIM workflow increasingly adopted by architects and engineers.

This however introduces a new problem; the precast industry typically works with its own hardware and software systems; these are typically a mix between manufacturing, construction, and precast-specific, or even proprietary systems. Even if an IDM becomes so comprehensive and successful as to be widely adopted by all stakeholders, a major challenge remains for the precast manufacturer: the BIM system must be maintained parallel to the existing production system, with all the cost regarding synchronization and parallel updating that this requires. An ideal alternative of course would be the expansion of BIM to cover manufacturing processes; however at the time, this does not appear to be something that the leading BIM software vendors are considering.

5.4 Transportation and Assembly

BIM can provide immediate benefits with regard to transportation and assembly, two key issues for precast concrete. Traditionally, these issues are dealt with via typical project and programme management tools; BIM software provides the potential for integration of such functionality within the greater workflow, thus allowing for greater transparency and involvement of stakeholders in the process. In addition, the capability for 4D modelling offered by BIM, allows for the development of detailed modelling and visualization of the construction process, something particularly useful for the assembly of precast elements. The possibility to integrate this within the existing BIM workflow should be an important development for the industry

6 CONCLUSIONS

Precast concrete, on par with other offsite construction technologies, has significant potential which so far has not been fully realised. The emergence of BIM as the dominant paradigm for IT in construction presents significant opportunities for the precast industry. A main aspect that has been identified in this paper involves the architectural and engineering design flexibility, with greater involvement of the clients' designers. In addition, the production, transportation, and assembly process can be greatly improved within a BIM workflow, providing optimization which the precast concrete industry could benefit from.

However major issues have to be addressed in order for these benefits to be realized. A combined effort by manufacturers, researchers, and software vendors will be needed. Key areas for future research and development involve interoperability, compatibility, and standardization, as well as the development of new software tools to take advantage of the capacity that BIM frameworks already provide.

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