A BIM Platform for Offsite Timber Construction

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This paper discusses the potential of a BIM platform for offsite timber construction within the context of the UK construction industry. It examines the benefits, limitations, and challenges that BIM brings for offsite timber. Proof-of-concept projects are presented that deal with the architectural technology, structural engineering, and life cycle analysis aspects. These demonstrate the feasibility of the development of an open BIM platform which would establish a common standard for the industry. The paper concludes by suggesting an alternative business model for offsite timber construction, as enabled by Building Information Modelling.

Keywords: *BIM, Offsite construction, Timber*

INTRODUCTION TO OFFSITE CONSTRUCTION

Over the past century, offsite construction has often been seen as an opportunity to bring to architecture, engineering, and construction (AEC) the tolerances, consistency, and advantages of scale that industrial engineering enjoys. Defined as the fabrication and assembly or pre-assembly of building elements, components or modules before transportation on site, it is typically believed to add substantial value to the delivery process (Miles and Whitehouse, 2013). However, what is labelled as offsite construction can vary widely. Generally, four levels of offsite construction can be identified: panelised (2d) systems, modular or volumetric (3d) systems, subassemblies and components (2d or 3d), and hybrid systems combining the above.

Within the offsite domain, timber systems hold a particular position. The most oft-quoted one is that of sustainability. Despite the current ubiquity of the term, this is often viewed narrowly, as a simple reduction of energy consumption or carbon emission figures.Timber systems that draw source material from appropriately managed forests can deliver significant environmental, technological, financial, and aesthetic benefits. Simultaneously, the ease of working with timber means that, unlike steel and concrete, offsite construction with timber becomes open to far smaller business entities. While concrete- and steel-based offsite systems tend to come from established conglomerates, the business ecosystem of offsite timber includes a substantial number of micro, small, and medium enterprises (SMEs).

MODERN METHODS OF CONSTRUCTION IN THE UK

The UK is a particularly interesting case with regard to timber offsite construction. Firstly, it is generally accepted that there is a housing shortage, while projections of future demand suggest that this will become more acute (Smith, 2015); the issue often makes it to the general press, where the construction industry typically reports that the desired targets are simply not achievable (Sharman, 2014).

At the same time, and despite having some of the most prominent AEC firms globally, the overall process and outputs of the greater construction industry is often judged as unsatisfactory, both by professionals and the general public. To that effect, the UK government conducts reviews or commissions reports, most prominent of which have been the 1998 Egan report, the 2004 Barker review and the 2008 BIM strategy. One of the foci of the Barker review was the use of Modern Methods of Construction (MMC), which were described as methods that improve both products and processes (2004). Many aspects of the review discussed policy and regulation issues, but from an AEC perspective greater uptake of technology was considered fundamental; today these are commonly understood as combining Building Information Modelling (BIM) with offsite construction.

Timber as a structural material has an increasing presence in the UK market. It is particularly popular in Scotland where timber platform frame has almost three quarters of the market share of new build housing. There is also capacity for closed panel systems that are internally lined, externally clad, and include services, windows, and doors. However, these are generally provided by SMEs and increasing in scale to the rest of the country poses particular challenges. BIM promises to address many of those.

BENEFITS AND CHALLENGES OF BIM FOR TIMBER OFFSITE CONSTRUCTION

A detailed review of timber offsite construction (Patlakas et al, 2015) has identified a number of areas where BIM can enhance the process; at the same time, the specialised nature of the industry brings particular challenges as there are requirements for interfacing with the manufacturing process as well as compete with the state-of-the-art in "traditional" onsite construction. These can be summarised as follows:

Increasing Design Flexibility

A recurrent issue of offsite construction in all materials has been a perceived lack of flexibility in the design process and, eventually, in the completed building. This is unsurprising; the strength of the industrial manufacturing process comes from standardization, which in turn means a limited range of options. Besides the obvious limitations to design creativity that this entails, there is the clear limitation in the fitness for purpose. Buildings are by definition one-off products, tailored to a specific site and, often, to the specific needs of a specific customer. The manufacturing-inspired standardisation has been often seen as a critical restriction by both designers and clients, resulting in limited response to user needs.

BIM can address this limitation partially by providing access to a vastly greater range of constituent parts. The capability of operating across the various levels of detail, from the micro level of an individual fastener to the macro level of a volumetric component, has the potential to allow for a much greater flexibility in the design while encouraging standardisation and offsite manufacturing where feasible or appropriate. The capacity to develop BIM objects with intelligent behaviour works to the benefit of offsite systems as their predetermined parameters can be incorporated automatically into the design, providing the designer with much more freedom without having to rely on external specialists.

Integration in the Offsite Manufacturing Process

The major implementation challenge comes mostly from the integration with the manufacturing process. Effectively this requires a definition of an additional schema or standard that would allow direct integration into the manufacturing process. While feasible in principle, so far there has been no commonly accepted paradigm. This is not an easy task; BIM is already facing obstacles with regard to a common standard and the "closed silo" approach taken by software vendors. Solutions such as the Industry Foundation Classes (IFC) hold some promise but they have obvious limitations (Redmond et al, 2012).

With offsite construction the complexity of the industrial manufacturing process comes to be added to that of standard BIM. Manufacturing is a separate domain with its own, typically highly developed, standards and schemata which often rely on software packages and systems alien to the AEC industry. What is more they have a far lower tolerance for unsuitability of formats. AEC today operates at best with a hybrid BIM process where some aspects are integrated in a BIM process while others remain external. Manufacturing does not allows this switch between formats; hence, if the benefits of offsite are to be realised fully, suitable standards will need to be developed. In this, timber offsite has a competitive advantage and can be a pioneer as its systems tend to be both simpler and smaller scale than those for concrete and steel.

Onsite Delivery, Assembly, and Erection Process

Poor workmanship has often been a criticism that offsite construction receives (Smith, 2011). Simultaneously, the onsite delivery and erection process is a main point for the economic feasibility and competitiveness of any method of construction. Existing BIM technology supports this process via nD modelling. In offsite manufacturing, all design components can be connected to a specific manufacturer, and thus project and programme management data can be linked directly into the model. That can provide a comparative advantage for offsite construction as opposed to standard methods were components in the model are producer-agnostic. At the same time, the inherent BIM capacity of full 3d visualization of all project components in all design stages can contribute to the training of onsite staff, allowing for fewer uncertainties and a better assembly process. As before, developing the appropriate standards, schemata, and input/output operations for those comes with its own significant challenges.

Structural Performance

The Input / Output (I/O) between the architectural and the structural part is a fundamental challenge for any successful BIM process. Timber systems pose additional difficulties due to the natural characteristics of the material, which is anisotropic and is affected by the moisture content and exhibits creep under sustained loading. Contemporary structural design codes, reflecting advances in research, have resulted in some particularly challenging design problems, especially in connections. The proprietary nature of many timber systems means that calculation tools are often tied to a specific producer.

A BIM process for offsite timber can address many of these issues. Many industrially manufactured components have precalculated structural properties (at the micro level of the individual fastener, this is always true) which is often expanded to specific arrangements (e.g. for joist spacings per span). While this approach is unlikely to achieve the optimization of a full bespoke structural analysis, it provides clear benefits in the schematic design stage.

Environmental Performance and Sustainability

The benefit from BIM here is not so much in improving the deliverable, as in providing designers with more information regarding the comparative advantages of offsite manufactured products. In particular for timber-based systems, whose sustainability advantages are well known and documented, this can provide an important boost and encourage more designers to utilise them in practice.

BIM PENETRATION IN THE UK TIMBER OFFSITE INDUSTRY

The UK has attracted a lot of attention by being the first country that declared an intention to make BIM mandatory for all government-procured projects by 2016. As this date is now very near, it would be expected that most, if not all, companies in the AEC sector would be ready; more so for the offsite sector where it is natural to assume that there is a greater interest in technological developments as part of an MMC strategy. A survey was conducted, including questionnaires and interviews, with representatives of 27 UK companies that specialise in the offsite timber sector (Hood, 2015). The survey included a combination of micro, small, and medium enterprises, which also reflected the diversity of the sector.

Interestingly, only 16 out of 27 companies reported currently using BIM. The respondents' understanding of the concept of Building Information Modelling itself, as described by the UK government, is itself debatable. Characteristically, 3 respondents (more than 10%) identified their level of BIM use as "Level 3". Given the NBS definition of a single shared project model, with access and modification rights by all parties, it is highly debatable that the respondents have indeed reached that level (the UK government's target for this is 2019). It is more likely that despite years of BIM discussion, many industry practitioners are still unaware of the terminology (probably understandably so).

The reasons that prevent greater BIM penetration are perhaps more interesting. While respondents overwhelmingly agreed (93%) that Information and Communication Technology (ICT) is given a high importance in their company, only 37% agreed that there is good company understanding of who delivers information, in what format, and in what time, and only 33% that there is good project information between project parties (Figures 1 and 2). A sizeable percentage (33%) are not satisfied with the software they currently use.

The interviews allowed participants to elaborate on these issues. Some of the representatives of the smaller companies failed to see the Return of Investment (ROI) benefits of BIM and do not intend to take it up, in line with previous research on the topic (Marasini and Patlakas, 2012). Those who are actually using BIM processes report that the quality control processes previously used with isolated CAD systems still need to be in place. The main benefit that participants associate with BIM is improved visualisation. This, however, is not a BIM-specific attribute, but simply a software function which is available in normal 3D CAD packages as well. It is likely that respondents confuse BIM as a process with specific software packages such as Autodesk Revit.

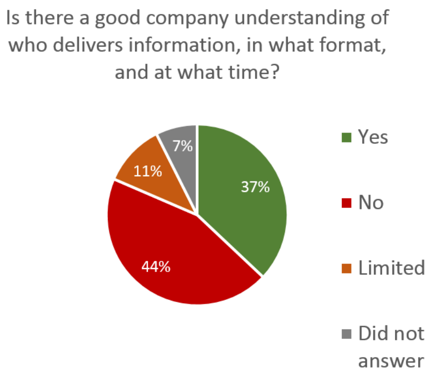

Figure 1
Responses regarding information delivery.

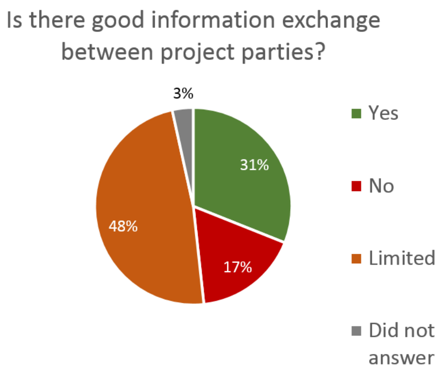

Figure 2
Responses on information exchange.

A recurring theme in all interviews was the lack of BIM to manufacturing interface, in line with the discussion in the previous chapter. The most characteristic example was provided by one respondent whose company utilises BIM-supporting software packages to adhere to client and architect demands, and then reproduces all documentation to standard CAD packages to adhere to the manufacturer's requirements. For such companies, BIM appears more as an additional production overhead than a rethinking of the design process.

PILOT STUDY OF COMPONENTS FOR A BIM LIBRARY FOR OFFSITE TIMBER

Architectural Technology aspects

A pilot study was undertaken at Southampton Solent University in order to demonstrate the possibilities from a library of BIM components (Beck, 2015). The architectural part concentrated on the demonstration of the capabilities of smart BIM components. The case study was based on a proprietary engineered joist system (JJI joists) for flat roofs and domestic floors. Based on the standard allowable loading values for domestic floors and flat roofs, the manufacturer provides specific span and spacing values. These were programmed into ready-made BIM components with the respective intelligent component behaviour (Figures 3-5). The min/max manufacturing limitations were also included. Future work will concentrate on integrating additional information such as cost and environmental performance attributes.

Structural Engineering aspects

The UK timber engineering practice is undergoing a period of transition, with Permissible Stress design codes, such as BS-5268-2 (BSI) being superseded by Limit State Design codes, such as Eurocode 5 (CEN, 2014). This transition brings timber design in line with other materials such as steel and concrete, allowing for an analytical approach that benefits from a transparent method of calculation, leading to design optimisation. It also allows for empirically validated strength values for both the material and the fasteners, which is directly applicable to the implementation of mass customisation (optimisation of standard components), and simplifies the use of new engineered solutions such as timber-concrete composites, structural insulated panels, engineered joists, cross laminated timber panels (CLT), dowel laminated timber, and glued laminated timber (glulam).

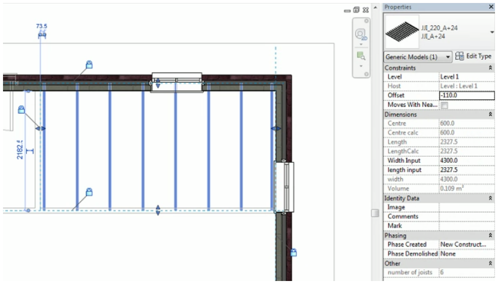

Figure 3
Inserting the BIM components in an existing model.

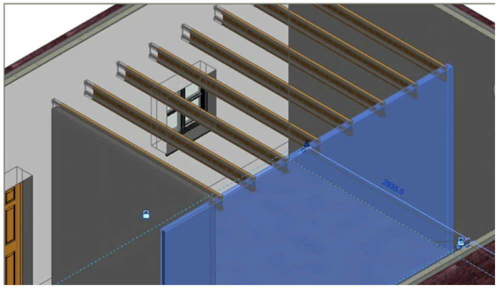

Figure 4
The spacings are calculated automatically based on the locked length.

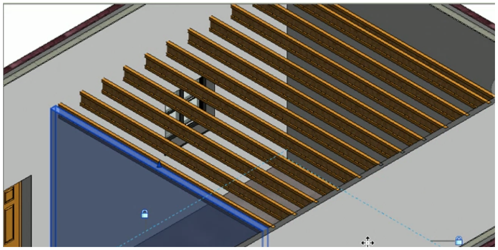

Figure 5
The spacings are automatically recalculated as the joist span changes.

The Centre for Offsite Construction + Innovative Structures (COCIS) at Edinburgh Napier University conducted a study to identify the barriers preventing the use and application of structural timber within the UK construction sector (Livingstone, 2015) whose results were in line with the findings from BDO (2013). In addition it attempted to identify the drivers for change for structural timber design, and make a case for mass customisation of structural timber design, in line with the offsite and MMC agenda.

There is, in general, a poor level of knowledge of timber and its applications in the UK. Despite the analytical benefits of Eurocode 5, the code is found to be overly complex by designers without training in the greater Eurocode design suite, and many perceive it as "not fit for purpose". This is partly understandable as the code does exhibit a certain level of engineering sophistication. However, the disparity here is highly likely to be due to lack of training and lack of calculation tools; the respective Eurocodes for concrete and steel have equal, if not higher, complexity, but do not appear to face similar levels of criticism.

The situation for offsite timber is further worsened by a lack of information relating to timber product and performance. There is a clear need for the standardisation of details, in particular those relating to commonly specified connections, where both design and built complexity reaches its peak.

By contrast, the non-timber offsite industries in the UK have demonstrated greater capacity for innovation and adaption, with regard to mass customisation, design for manufacture and assembly, as well as BIM integration. This is primarily a consequence of the fragmentation of the structural timber supply chain which leads to significant differences in investment into research and development. This disparity results in the following shortfalls within the UK timber industry:

- The quality and accessibility of data to support modern wood building solutions and their associated design processes.
- Establishing standardised design and detailing and communication of best practice.
- Effective dissemination of academic research to practising structural engineers.

Building Information Modelling tools for timber structures, while having advanced in the last two years, still show a disparity with those available for steel and concrete. As part of an ongoing research project COCIS is building upon the existing research to develop a robust and credible open access BIM data platform for the UK AEC sector. This involves collating the appropriate findings of historic and ongoing structural timber research, as well as parsing calculated engineering data, including life cycle analysis information.

The two main aspects that are investigated include the key areas of significant for offsite timber. The first deals with the structural design aspects: it is based on structural calculation software developed by the authors (COCIS calculations for TEKLA Tedds; Teretron). These include tools for the structural design of individual members, connections, and components such as timber frame racking wall panels.

The latter provide a good example of such a dataset. Timber frame racking panels are commonly used in low-rise housing and in some nondomestic low-rise situations. This dataset has a large number of parameters, a few of which are listed here: the construction of the wall panel can be open or closed; the sheathing material is specified; along with the fixing type which is sheathing material dependent with the specified spacings; there is a selection of commonly available timber grades; the soleplate connections can be chosen with details including straps and brackets; and a selection can be made of the permanent loads onto the wall head, etc (Figure 6).

A second aspect is that of Life Cycle Analysis data (LCA). The sustainability benefits of timber are, on principle, known to designers. However, it is not always possible to get hard data to back this up. The LCA data bank aims to change that by providing information that can be used by designers in their communications to clients.

This research will lead to the creation of very large BIM enabled data sets. These will directly feed into smart BIM components, which will be capable of communicating the industry-required data for design and sustainable specification of new timber and timber-related products. These tools will create an easy route to take research information straight into BIM enabled software platforms, while responding to the requirement of the AEC industry for robust and preapproved design details. A schematic representation of the Smart BIM Component strategy is given in Figure 7.

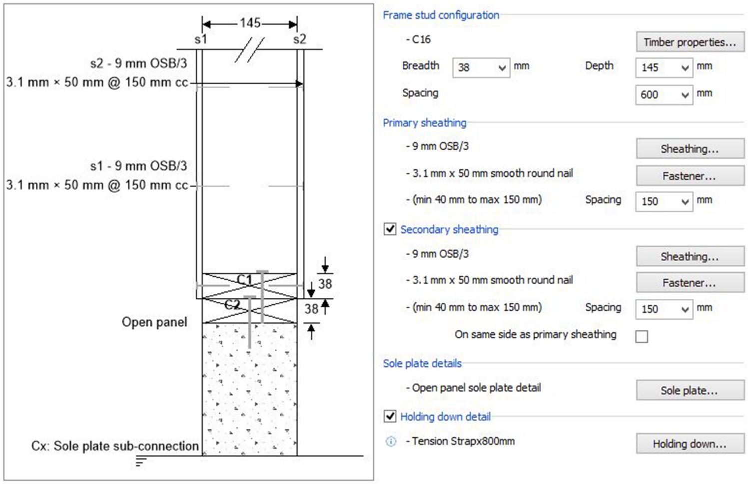

Figure 6
Tedds calculations for racking walls developed by COCIS.

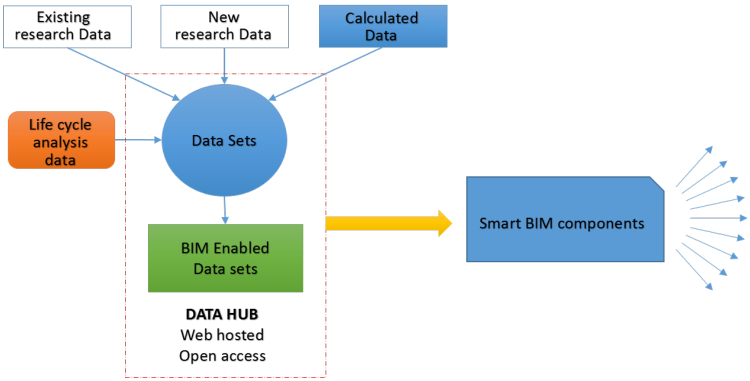

Figure 7
Schematic representation of BIM dataset development.

AN ALTERNATIVE MODEL FOR OFFSITE TIMBER

The research has shown that there are both clear benefits and clear limitations from utilising a BIM process on offsite. It can provide greater design flexibility; it can enhance design flexibility; it can provide the designer with much more information, reducing or eliminating the need for specialised (and expensive) consultants, at least on the schematic design stage; potentially, it can also improve the onsite assembly and erection process. The main technological limitation is the lack of any standard or framework for transition from design to manufacturing.

Perhaps surprisingly, a second obstacle, at least in the UK, appears to come from the approach of many offsite timber specialists. There is a strong tendency towards a "closed silo" mentality; many specialists function as "all-in" providers, with in-house designers, engineers, technologists and, often, manufacturing facilities. For larger concerns this can also include their own small software packages, specifically for their proprietary products. Smaller-scale companies might work via exclusive deals with specific manufacturers or producers of components.

This closed approach is unlikely to be beneficial for the offsite timber industry in the long run. It exacerbates the oft-criticised lack of design flexibility, while it ties smaller companies to bigger manufacturers restricting both creativity and innovation. Historically, such market models tend to lead to concentration to a few big players and eventual eradication of SMEs from the market, due inability to respond either to client requirements or increasing regulation.

It is possible that, in trying to replicate the practices of manufacturing, the offsite industry has chosen the wrong model. Architecture is a site-specific one-off process and unlikely to be fulfilled by the product engineering model. Perhaps the successful analogy is with the software industry, where software engineers can choose to incorporate in their application snippets, libraries, or modules; utilise existing programming interfaces; conform to certain schemata or frameworks. In principle, there is no reason why the timber offsite industry cannot follow the same model: manufacturers can operate on the different levels of offsite (from the manufacturing to the volumetric), assembling and combining products. The positive aspects of offsite, such as standardisation and high quality of manufacturing, can be utilised, without losing on design flexibility and restricting technological innovation and design creativity.

BIM provides the opportunity to realise this an alternative model. If successfully implemented, this could enable significant growth of the sector, while preserving and enhancing the variety of the current business ecosystem. The fundamental requirements for this to proceed consist of a framework for the aforementioned BIM-to-manufacturing linkage and, more importantly, a common framework for a BIM process.

The latter is of course an ongoing issue within the greater AEC community and perhaps the greatest barrier for implementing BIM Level 3. It should be possible, however, to attempt this standardisation within the much smaller domain of the timber offsite community, thus unlocking the BIM/MMC potential.

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