A STRUCTURAL ENGINEERING PLATFORM FOR TIMBER MODERN METHODS OF CONSTRUCTION

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ABSTRACT

The UK has a housing deficit, requiring 3 million new homes by 2020 that will have to conform to national environmental policy and the corresponding regional building regulation requirements. The economic down turn has exacerbated this problem and as a result there is now an even greater need to employ an offsite Modern Method of Construction (MMC) approach.

The current implementation of innovative timber offsite MMC techniques is limited due to the lack of availability of a Eurocode compliant software platform that is generic across the Architecture, Engineering and Construction (AEC) sector. This constraint was identified when timber engineering innovations were restricted from being embedded into practice after being developed with architectural firms and construction companies.

As a result the Centre for Off-site Construction and Innovative Structures (COCIS) at the Institute of Sustainable Construction (ISC), Edinburgh Napier University is currently developing an integrated whole house engineering (WHE) system based on Tedds® for Word (Tedds), CSC Inc. The system being developed has the capability to harness the findings of research work being undertaken and embed them into practice whilst being compatible with future building regulatory standards and construction practices.

This paper provides an overview of the above process and through a case study demonstrates how the software platform being created is resulting in the practical application of research work being undertaken in collaboration with industry partners. Additionally, consideration is given as to how the software can be enhanced further in the future to be Building Information Modelling (BIM) enabled.

Keywords: BIM, modern methods of construction, structural optimisation**,** timber design.

1 INTRODUCTION

The total amount of materials required for construction purposes in Europe exceeds 2 billion tonnes per year, making it the largest raw material consuming industry accounting for about 5% of energy used, including related transport. The buildings that are constructed as part of this, consume approximately 42% of all energy used via heating and lighting from fossil fuels (ECTP, 2005). The EU is committed to reducing overall emissions by 30% below 1990 levels by 2020. Therefore, construction will have to become more sustainable both in terms of the materials it uses, the methods it applies and the systems it produces.

The UK, as a member state, is part of this commitment and although there are regional policy variations there is a unilateral drive towards more sustainable communities formed from sustainable construction methods. To achieve this it is important to learn from the past, endorse the correct practices and employ the correct methodologies. This requires a holistic approach with design (including material and system selection) at the centre of the process.

Timber offsite Modern Methods of Construction (MMC) is a viable solution given the need to produce more for less without impinging upon the ability of future generations. Timber for construction purposes in the UK is primarily used for low to medium rise construction, and the vast majority is imported. Currently, the home grown resource of the UK is predominantly used in low value products (fences, pallets and packaging) but could feasibly be used within an overall more sustainable construction process (Moore, 2011). There is historical evidence of the UK using available timber resources for methods of construction applicable to its inherent nature, such as cruck, box frame and post and truss. Of course the forest resource has somewhat changed due to forestry policy including the forestation with non-indigenous species such as Sitka spruce. As a result, new modern forms of engineering and construction need to be considered in order to exploit this commercially available timber resource in higher value added end products for the construction industry.

To achieve this, the relative advantages and disadvantages of the different forms of timber offsite MMC must be understood and going forward new technological advances must be further exploited. Critically, the industry has to understand the opportunities that are available and embrace the key concepts of the MMC ethos. Notwithstanding, the AEC sector together with the timber industry must be provided with viable design aided tools in order to facilitate the knowledge transfer from the research stage to the final market and enable data sharing instead of data exchange (Osterrieder, et al., 2004). The work being undertaken by COCIS in collaboration with CSC (UK) Ltd is developing such a mechanism in order to streamline the release of research findings to the AEC sector and in particular release information on work carried out on new UK timber components and systems and their associated details.

2 BACKGROUND

AEC timber related software and prospects

There is a large catalogue of AEC software products concentrated mainly on steel and concrete building design in contrast with the limited range of products capable of providing an element of structural timber design (Table 1). The use and application of these tools is further limited when considering the use of modern timber connections, components and systems such as propriety metal work, Engineered Wood Products (EWPs) and advanced closed panels such as those incorporating services or renewable energy technologies. Correspondingly, there is modest use made of advanced computer aid tools in the timber sector (Palmer, 2000) and indeed the use is normally fragmented.

Table 1 List of design software for timber structures

Name	Timber design code	Language	Timber WHE design	2D/3D CAM	BIM	Cost
IES VisualAnalysis	NDS	E	No	2D/3D	Via Revit	6,950$
Bautext (Wood module)	DIN, EC5	E, G	No	No	No	1,300$
Dlubal (TimberPro.X)	DIN, EC5	E, G	No	2D/3D	No	1,650$
Dietrich's (D-Wall)	DIN, EC5	Multiple	Yes	2D/3D CAM	Not fully	N/A
RUNET (Woodexpress)	EC5	Multiple	No	2D	No	850$
Weto (Viskon V5)	DIN	G	Yes	2D/3D CAM	Not fully	6,700$
Technosoft (AxisVM)	EC5	Multiple	No	2D/3D	Not fully	N/A
RISA 3D	NDS	E	No	2D/3D	Via Revit	3,000$
Autodesk (Robot Analysis)	Multiple	Multiple	No	2D/3D	Via Revit	4,500$
CSC Inc (TEDDS)	Multiple	E	No	2D	No	4,850$
TRADA (TimberPro)	EC5	E	No	2D	No	475$
Timber design code: NDS (National Design Specifications, US) DIN (DIN 4074, Germany), EC5 (Eurocode 5). Language: E (English), G (German). Approx cost in USD tax inclusive.						

Other available timber engineering related proprietary software used in the UK is currently provided, usually free of charge, by manufacturers of EWPs or metal plate connections. These design tools do not provide design flexibility as they are restricted to the products of the manufacturer. The internal programming system is a 'black box' where the material selection, the method of construction or the design code of practice is normally hidden and not open for amendment. This restricts engineering judgement and commoditises the process. Finally, the capability to import or export information across other software platforms is very limited and as a result, Building Information Modelling (BIM) processing and the capability to apply a holistic design approach is restricted. At the same time, the market share of timber in construction is growing due to future building regulation requirements, government sustainability policies, the advantages of off-site timber MMC (Hairstans, 2010) and the increasing demand from architects and clients for EWPs (Wilson, 2007) . Given that this is the case, there is discernible need for an AEC compatible timber design tool with integrated flexible databases.

In addition to the above, the recent publication of the Eurocodes and its inclusion in the UK building regulations requires timber design processes to be Eurocode compliant. The shift to Eurocodes is more onerous in the UK when considering timber design given the need to migrate from a permissible stress approach (British Standard Institution, 1996) to a limit state design approach (British Standard Institution, 2006). Eurocode is also a more analytical approach to design facilitating innovation and system evolution; however, it is also a more onerous code to use requiring the need for easy to use yet transparent design tools.

Timber research knowledge transfer

Research related to structural timber engineering commonly results in new design methods (Hu & Chui, 2004), new structural timber based materials (Brunner, et al., 2007) or innovative methods of timber construction (Smith, et al., 2011). The findings of the research are generally disseminated in the form of publications (scientific books, journal papers or articles), seminars or conference proceedings. Therefore, although this work is of great value, there is an elongated timeline to utilisation due to traditional dissemination being employed. In addition to this, the application of innovation in the construction industry is difficult often due to a lack of available information, confidence in the product or detail and technical compatibility issues (acoustic and thermal performance or production and construction processes). The timber sector is not an exception and any innovative solution frequently requires a long transitional process through all of the industry levels.

The British government through programmes such as Knowledge Transfer Partnerships (KTP) is helping organisations to improve competitiveness and productivity through a better use of knowledge, skills and technology from research organisations. Similarly, governmental research council agencies such as the Engineering and Physical Science Research Council (EPSRC) are also funding projects proposed by higher education institutes in relationship with industrial partners.

The Centre for Offsite Construction and Innovative Structures (COCIS) at Edinburgh Napier University is working strategically with a number of partners to innovatively evolve timber construction to become an offsite MMC. As part of this process the centre was awarded a two year project entitled “Structural Optimisation of Timber Offsite MMC” by EPSRC which commenced in June 2011. The purpose of the project is to derive through testing in isolation and in combination novel technical solutions and innovative products for offsite MMC. The work presented in this paper is part of this funded project and demonstrates the research impact created by developing a Tedds based platform in partnership with CSC (UK) Ltd.

3 METHODOLOGY AND CASE STUDY

A key objective of the EPSRC project is to produce a WHE mechanism based on Tedds that is cross correlated with Eurocode design procedures and capable of exploiting a comprehensive database that can be interfaced with other software applications. The database can be populated with either generic information from available standards and manufacturer literature or obtained through United Kingdom Accreditation Service (UKAS) laboratory testing. The Tedds proformas use information extracted from the database to provide Eurocode compliant design calculations that are fully transparent and can therefore be externally verified. Finally, though collaborating with CSC (UK) Ltd, the information can be distributed directly to a targeted audience hence streamlining the access of practicing engineers to innovation (Figure 1).

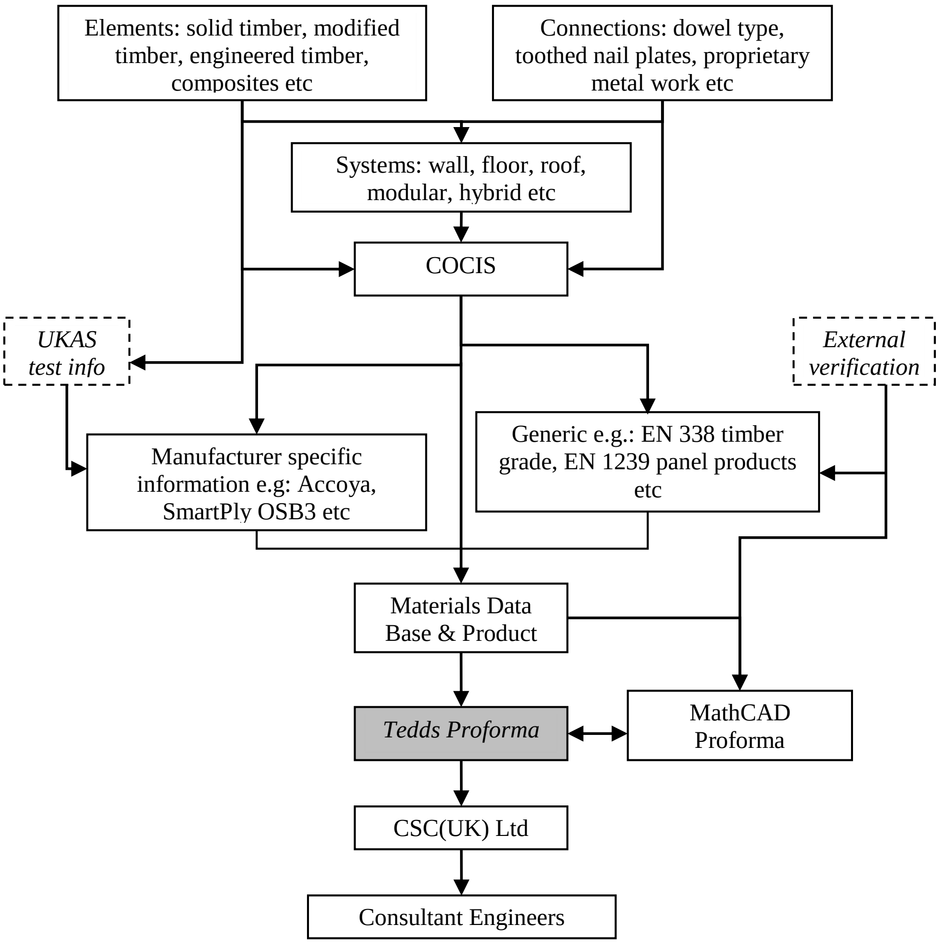

Figure 1 EPSRC Project Flow strategy

Development of WHE platform

The structure of the WHE mechanism can be defined as a group of components or proformas that use a core centralised database of collated information. The database retains the material, component or system performance information and the proformas process this according to the function to be designed for (roof, floor or wall) which when combined provide a WHE solution.

Figure 2a shows the different components of the integrated WHE concept. These components are able to both stand alone and to interlink with other WHE proformas. The information contained within the generated WHE database is shown in Figure 2b. The database can be product specific, product generic or research specific in order to facilitate the subsequent parametric analysis process to optimise the final structural design. The database also has the potential to be BIM enabled as information can be imported or exported from other software such as Microsoft© Excel.

The programming language used to generate Tedds proformas is a composition of Visual Basic for Applications (VBA) and C++. Nevertheless, CSC (UK) Ltd, as a result of a collaborative agreement, has provided COCIS with its professional developer software package (PDP). This tool facilitates the creation of professional sets of calculations with refined graphic user-friendly interfaces (GUI).

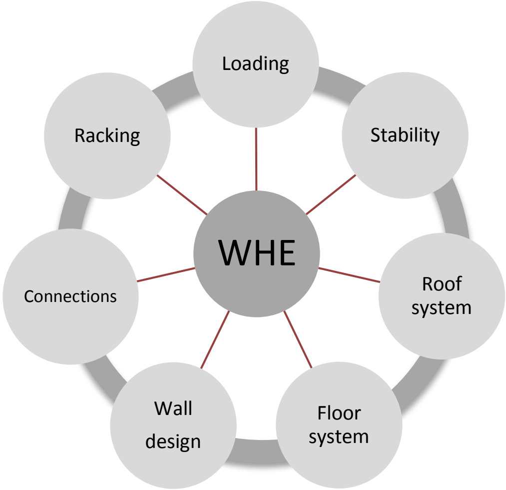

Figure 2a WHE mechanism concept

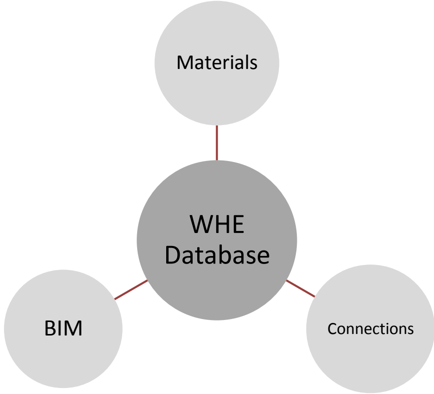

Figure 2b WHE Database information

The methodology to develop a new proforma from the WHE concept begins by defining a unique flow chart. This is generated from the Calc Designer tool (included in the PDP). The flow chart created follows an *intelligent sequence* managed by the GUI that streamlines possible amendment, checking or verification processes. Every stage of the flow chart relates to a *mini-block* or reduced calculation section previously recorded in Tedds. These sections can be structural calculations, active 2D drawings, static 2D/3D sketches, interfaces, guidance notes or supplementary language code. Additional information is described by the case study presented in the next section.

The output achieved (Figure 3) after developing and running the application is a 'Calc-pad' style word document aligned with the analogy of spreadsheets but without the issues associated with them such as transparency or partial built-in checks (Institution of Structural Engineers, 2002).

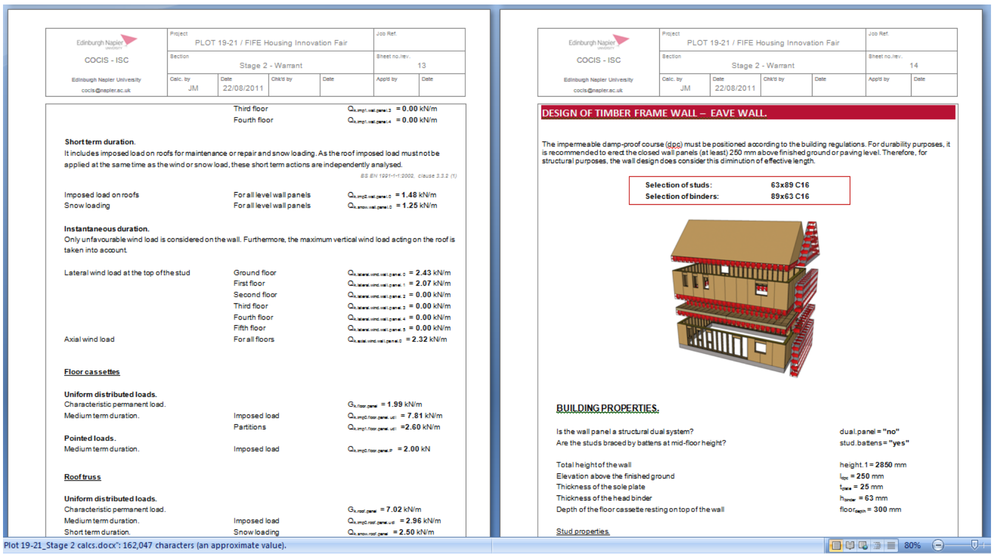

Figure 3 Example proforma output (screenshot)

A comprehensive list containing all of the unique variable names and units defined in the WHE mechanism is recorded as this can be required for referencing at any time. The variable names are also used to populate the databases with relevant information.

Case study: Racking design proforma

COCIS has been engaged in a research programme since 2008 investigating the structural racking behaviour of timber frame shear walls. In 2008 there were two Eurcode design methods for racking performance designate A&B neither of which were compatible with standard UK timber frame construction practice (TRADA, 2007). The research work undertaken by COCIS has included extensive laboratory testing and analytical review of timber frame racking wall behaviour employing modern fabrication techniques. The findings from the research work have contributed to the British Standard Institution (BSI) committee (as responsible for the implementation of Eurocode 5 in the UK) in the development of a third Eurocode 5 compatible racking design method for the UK (Leitch & Hairstans, 2010). This third method is expected to be published as complimentary document PD6693-1 and to be referenced as an acceptable alternative in the Eurocode 5 - National Annex (NA).

In addition to the above, and as part of the EPSRC project, process data and findings from the research work undertaken on racking have been collated and embedded in a Tedds database (Figure 4) and racking proforma. Particularly, both generic and specific information related to the mechanical properties of sheathing board, timber sections and fasteners and to the load carrying capacity of anchorage methods is included.

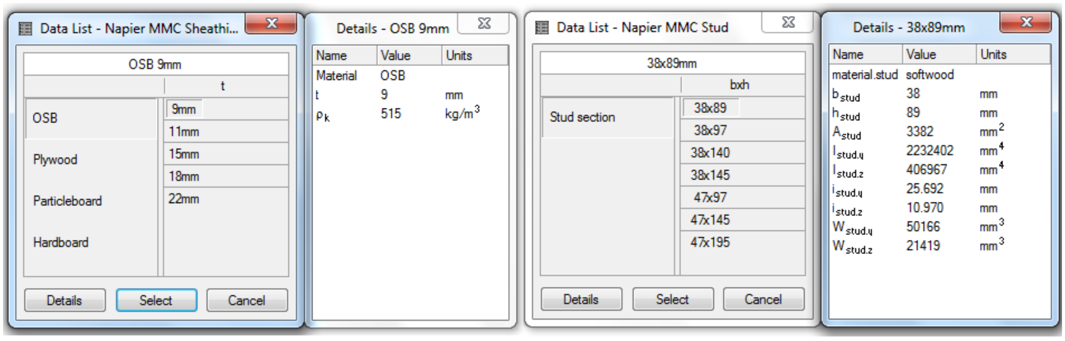

Figure 4 Product - generic databases for racking proforma

Figure 5 shows a graphic view of the racking flow chart proforma created from the research knowledge. This flow chart was created by Calc Designer (PDP, CSC Inc.) where each of the thirty-six brown boxes is associated with a calculation section or *mini-block* previously defined in Tedds. Calculation components are connected by logical expressions.

The flow chart is internally managed by the GUI (Figure 6). Interfaces are created by Interface Designer, PDP, CSC Inc. The programming language is C++ and the interface also allows for active 2D drawings which assist in the design process by making it visually interactive. An additional advantage of the proformas is their ability to inform the user of methodology employed, factors applied or variables considered via explanatory notes and captions.

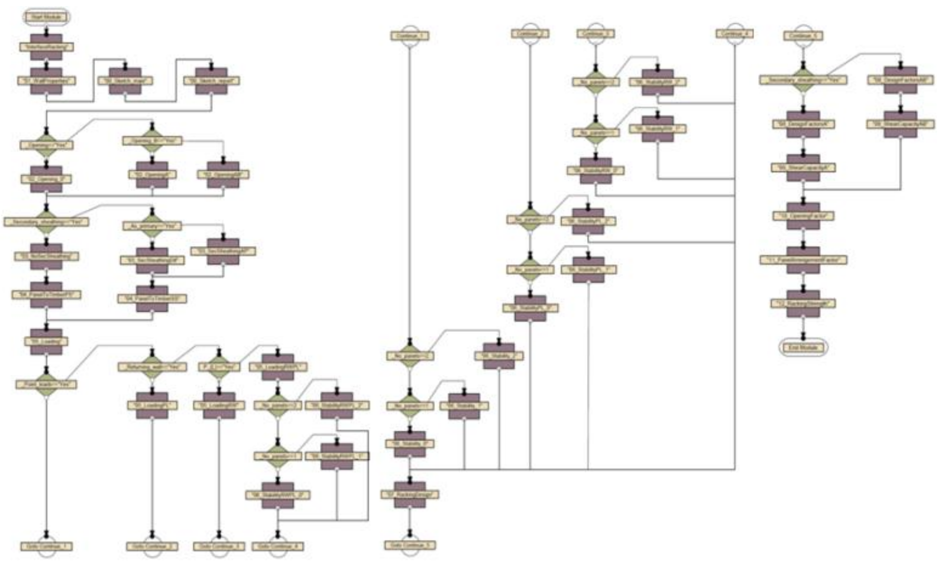

Figure 5 Racking proforma flow chart created with Calc Designer.

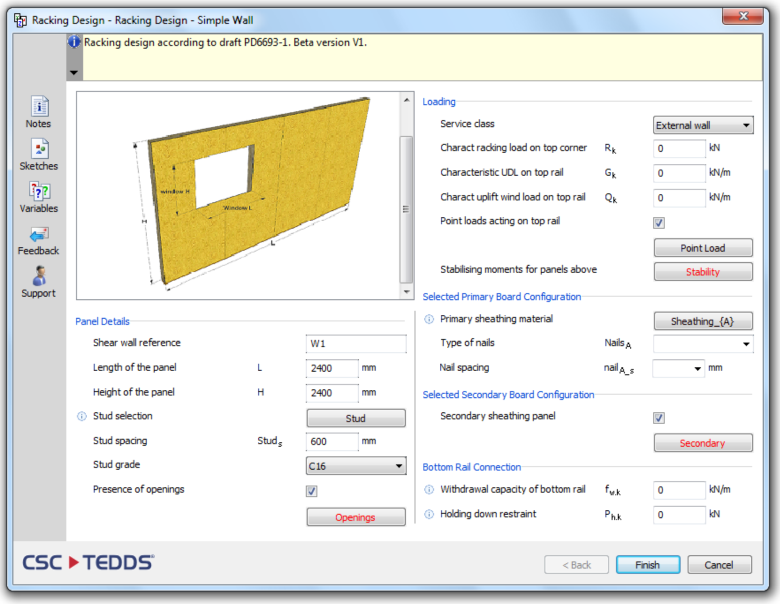

Figure 6 Racking interface created with Interface Designer

This active interface enables the user (architect, engineer, timber designer, manufacturer, researcher, etc.) to calculate the racking strength value in real design time. Consequently, the user is able to optimise the performance of the shear wall according to different variables such as sheathing material and thickness, sheathing fastener pattern or sole plate fixing detail. The proforma created also allows the designer to use data obtained by testing as this can be included in the WHE system product library. This proforma approach accelerates the process of efficiently evolving the wall panel design in terms of performance and cost by carrying out parametric analysis. Additionally the proforma can guide the user to conform with code requirements such as in cases that input values are not within the limitations given by the design code, e.g. window opening distances, diameter of fasteners or spacing of fasteners, a pop up error message will be displayed.

Once the user approves the final design, the proforma will automatically create a comprehensive structural report in Microsoft© Word format which is fully transparent and can be externally verified. Internally, the proformas are being verified via cross correlation to Mathcad© and Microsoft© Excel templates as applicable.

4 CONCLUSION AND FURTHER RESEARCH

Due to a significant housing deficit in the UK and the sustainable credentials of timber, there is an opportunity for timber offsite MMC to expand in the future. In particular there is as a potential for more UK grown timber to be used in higher end value construction products as a result of on-going research in this area, primarily at Edinburgh Napier University. However, the impact of this research investment is currently limited due to the lack of available AEC software platforms for the generic design and detailing of timber systems to Eurocode.

The overarching aim of a current EPSRC funded project hosted by COCIS is to develop a structural optimisation platform for timber off-site MMC. This platform will not only provide a Eurocode compliant design mechanism for timber but also link the findings from research investment with the end user via Tedds.

The case study contained within this paper demonstrates how the findings of an extensive programme of research work can be embedded into structural engineering practice via Tedds. The integrated platform has been standardised in accordance with the requirements of the, to be released, UK Eurocode compatible design method. The software, through use of a comprehensive database, also has the flexibility to undertake diverse analytical review of available systems. In addition to this, the transparency of the system allows external verification to be simplified.

The work reported in this paper is part of ongoing research work to develop a whole house engineering mechanism capable of ensuring the impact of research findings into structural performance. However, the structural design platform being created can, through its generic database, also be integrated with additional information where a holistic design approach is required including for example cost and building performance (thermal and acoustic). As a result, the system being created has the potential to provide architects, engineers, quantity surveyors, building planners, local authorities and the timber industry in general with reliable valuable information of timber built systems. Given the above, the long term aim is for the software platform being developed to become BIM enabled by the inclusion of relevant information to the product library with assistance from industrial partners.

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