Offsite Construction: Sustainable Innovation Futures Using SMART Approaches

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Abstract

Offsite manufacturing has been advocated as a potential lever for addressing the increased emphasis placed on construction stakeholders to meet the challenges of sustainable construction. These challenges include a myriad of issues ranging from green agenda-driven polices and initiatives, through to new strategies and formal mechanisms that are purposefully aligned to meet sustainable metrics and indicators. Whilst it is acknowledged that construction (*inter alia*) has been somewhat entrenched in a raft of potential 'ways forward', the resurgence of new collaborative approaches using technology – especially Building Information Modelling and SMART components provides promising opportunities for exploitation. This research presents an illustration of the potential to integrate design, development and delivery of products and services using offsite construction as an exemplar. The research methodological approach adopted employed a mixed-method research design, which included a series of discursive on-line interviews with domain experts to collect primary data, followed by a workshop to validate findings. These findings emphasised the importance of providing information 'transparency' in order to fully maximise and exploit offsite manufacturing technologies and processes to not only leverage success *per se*, but also enhance the collaborative working practices of (seemingly) disparate stakeholders.

Keywords: Modern Methods of Construction, Offsite Manufacturing, SMART Components, Process, Technology

Introduction

The terms "manufactured construction", "off-site construction", "off-site manufacturing", "industrialised building systems" "off-site fabrication" and "modern methods of construction" have all been used interchangeably in extant literature to describe pre-fabrication within construction. Whilst it can be argued that some have these terms have distinct differences

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(Gibb and Pendlebury, 2006; Nadim and Goulding, 2011), ostensibly, the underlying focus of these ‘umbrella’ terms is to capture the message of moving some of the construction effort into a controlled environment, using manufacturing facilities. Notwithstanding these differences in nomenclature, offsite manufacturing (OSM) has been acknowledged as being able to procure specific benefits, which include higher speeds of construction, enhanced quality outputs and tolerances, lower costs, and reduced on-site labour re-work (Schuler, 2003; Mullens and Arif, 2006). These espoused benefits have been evidenced in a number of countries, not least Japan (Gann, 1996), the USA (HAC, 2012), the UK (Taylor, 2010; Buildoffsite.com; Egan, 1994), Malaysia (CIDB, 2006), and Australia (Hampson and Brandon, 2004).

However, despite all these espoused benefits and supportive global initiatives, the uptake and pervasiveness of offsite manufacturing is much slower than expected, with a market share in the UK being reported to be around 6% (Taylor, 2010); yet the UK the construction industry sector contributes approximately 8% of the country’s Gross Domestic Product and has over 250,000 enterprises, with an annual turnover of £100bn (ONS, 2012). This GDP relationship broadly proportional to other countries over the world, which therefore suggests that the market has potential to benefit from OSM approaches. In addition, extant literature advocates an increased need to employ cutting-edge technologies to address the emerging challenges introduced by the global Architecture Engineering Construction (AEC) projects. Acknowledging this, it is also important to note here that information and communication technology (ICT) has revolutionised production and design (Cerea, et al, 2002), which has led to dramatic changes in terms of production materials and labour (Fruchter et al, 2000; Akintoye et al, 2012). Moreover, the increased use of ICT tools within design and construction now enables designers to experiment and experience OSM decisions in a ‘cyber-safe’ environment in order to mitigate or reduce risks prior to construction (Goulding et al, 2012). This rapid growth of technology adoption and absorption has been widely evidenced in several other industries; but the same cannot be said for the construction industry with its disparate supply chain and on-site/off-site information flows. However, there are some promising emerging ICT enabled approaches, e.g. Building Information Modelling (BIM), which could support a comprehensive digital representation of all construction information for various stages of the project lifecycle and also enhance team collaboration/project integration (Gu and London, (2010). Given these developments in ICT and OSM opportunities, Taylor (2010) noted that an industrialised system of construction could provide “affordable quality homes” which may help overcome some of the major problems inherent with the traditional approach to construction. In addition, “There is a growing body of evidence to prove that OSM, Modern Methods of Construction (MMC) and Design for Manufacture (DfM) can impact significantly on waste whilst delivering great architecture with corresponding savings” (Davis Langdon, 2011). In summary therefore, acknowledging these issues, and the potential for offsite production and manufacturing to make a positive contribution to AEC stakeholders, it is posited that there is an exigent need to identify the core preventative barriers to uptake and adoption; for example, culture, demand-supply production models, new business strategies etc. This reflection also needs to embrace the inclusion of SMART components, as the integration of these can help provide meaningful solutions to designers (new options), manufacturers (integration), constructors (flexibility), and the end users (adaptability).

SMART Components and Connectors

The term “SMART” component is metaphor applied to any prefabricated frame, panel, technology or connector engineered to integrate with traditional or proprietary technologies. They can be manufactured from a wide range of materials to suit a variety of particular needs (loading, scale, maintenance etc). SMART components are also uniquely customisable to meet customer-specific applications, as the options they afford provide architects and engineers with maximised design and construction flexibility. Thus, the design and development of the SMART components can be said to combine ambient manufacturing methods with an open system for products and components. This offers direct ‘plug and fix’ capabilities, which from and OSM perspective, provides flexible design solutions of a particular space to cater for the needs of the occupants over time. Thus, when designing systems for offsite manufacture, it is important to engage all relevant stakeholders at the early design stage in order to ensure that the end product meets all requirements. These stakeholders typically include: end-users, clients, architects, engineers, builders and manufacturers. It is also important to consider the varying levels of componentisation or manufacture that is to be taken offsite.

SMART components are therefore distinctly designed to be multi-purpose, multi-functional, and offer maximum in-use adaptability – as the re-configuration of space over time can easily be accommodated with minimal damage to the fabric. The design of these components therefore needs to consider:

- The holistic design process - specifications and performance levels must be determined prior to development;
- Cradle to grave thinking - building lifecycle (circa 1500 years?);
- Standards and technical conformance – certification and conformance often varies from country to country;
- Performance – stakeholder requirements (delivery, constructability, in-service use, maintenance, demountability, disposal etc).

One of the major challenges with pre-fabrication and OSM is not the components themselves per se, but rather, the interface between different elements of the system. For example, re-configurable spaces can be made for changing needs thorough such products as Push Walls and the Demountable Walls, fixed by pressure which can be easily moved without specialist skills or tools. Materials such as fibre reinforced plastics (FRP) have been successfully used in the construction sector from the early 1990’s, and have been widely used in the transport and aeronautical industries. FRP’s consist of a polymeric matrix reinforced with fibres, and are generally made from materials such as carbon, boron and resin. Products include small pre-formed units and structural elements for houses, through to large load-bearing elements of buildings, bridges etc. As FRP is significantly lighter than conventional materials, the use of heavy machinery on-site can be reduced or avoided in certain circumstances. Constructability has also been advocated as being up to 70% shorter than by conventional methods, which can help reduce the incidence of construction-related accidents on site. Examples of this approach include partition walls which do not require a frame or sub-structure, as the walls are fitted to connectors that have been fixed to the ceiling and floor. Several commercial systems are available e.g. Quicklock Partitions (Quicklockpartitions, 2012), and a variety different connector systems can be used (in many different combinations), including magnetic connectors, plastic connectors, steel connectors etc. Commercially available connectors include several options, from the Keku connector - Figure 1, which can be used to secure trims and cladding panels directly to walls with no wooden subframe; through to Velcro tape (produced by 3M) for rapid assembly and disassembly.

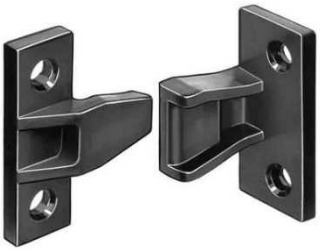

Figure 1: Keku push fit fastener set (©Keku)

Other rapid connectors include Dipple Klick – Figure 2, which was developed by Corus (now Tata Steel) through ManuBuild (ManuBuild, 2009) as a rapid connection solution for offsite (manufacturing and buildability). Dipple Klick is a junction between two cold-formed sections, designed as an interface between wall panels, but extendable to floor, ceiling and roof elements. The main drivers for the development of this connector were:

- Improved flexibility, increased accuracy and building tolerance;
- Reduced tooling (lower capital investment) and reduced setting-out times;
- Higher quality product;
- Accuracy – greater reliability and repeatability of the process;
- Improved health and safety aspects.

Figure 2: Dipple Klick rapid connector (©Tata Steel)

In summary, SMART components offer a range of benefits, not least: greater connectivity options, improved accuracy (tolerance), enhanced flexibility options etc. However, these issues do not naturally seem to have been overtly captured when considering the fundamental nuances of on-site v offsite construction. Given this, it was considered important to investigate these through the Design, Manufacturing and Construction stages, mapped against process, technology and people issues.

Research Methodology

This study specifically focuses on the socio-political-technical relationships that affect the uptake and adoption of OSM. It adopted an interpretive approach to positioning, as it sought to uncover new meanings and constructs. The research methodological approach adopted used a mixed-method research design, which included a series of discursive on-line interviews through three webinars with domain experts to collect primary data. These findings were then presented in a formal workshop, where the results were explored in depth. Initially, the causal problems and key issues that impinged upon the successful uptake of OSM were identified through extant literature over the last 20 years. The temporal timeframe reflects relevance and proximity, and the research lens was open-bounded, thereby not constrained by context, regional or geographical issues. Three areas were selected (Process, Technology, People) cutting across three sectors (Design, Manufacturing, Construction). These six areas were identified as the main units of analysis.

This data collection was undertaken as part of CIB Task Group 74 remit – to investigate new business models in offsite construction. The webinars and workshop were attended by academics and senior executives from companies engaged in offsite construction. These survey participants were ‘representative’ in order to establish, evaluate and prioritise these nine areas into a draft framework of issues for future uptake. In terms of the methodological approach, this stage followed guidelines for collecting data through focus-group-workshops. Prior to conducting the workshop, the issues of the study were clearly articulated and the questions predetermined (Cresswell, 2009) aligned to the aim of the research. This method is often characterised with its clear use of group communication to generate data and thoughts that would not be easily accessible via ordinary individual interviews (Morgan, 1997; Parker and Tritter, 2006). Hence, this was considered an efficient approach for generating ideas and solutions based on the experts’ consensus. Three central ‘themes’ of People, Process, and Technology (see Davenport, 1992) were used in the development of this study, mapped against Design, Manufacturing and Construction (the three dominant paradigms drivers of offsite).

Research Findings

The research findings presented below highlight the main findings from the three online webinars and formal workshop. These cover the nine interrelationships (Table 1), reflecting *Design-Process*: *Manufacturing-Process: Construction-Process*: *Design-Technology*: *Manufacturing-Technology*: *Construction-Technology: Design-People*: *Manufacturing-People*: and Construction-People respectively. The primary data was coded and analysed using content analysis to provide the main focus areas. A brief discussion of these relationships follows.

Table 1: Nine OSM themes

	Design	Manufacturing	Construction
Process	Adding Value	Flexibility	New Business Models
Technology	Exploitation	Justifiable Automation	Risk Identification
People	DfMA Skills	Manufacturing Needs	Productivity Up-skilling

Design-Process: Adding value to the business process (multiple perspectives); Process Protocol – lifecycle processes, tried and tested (concentrate on the most important ones); stakeholder analysis is needed; understand the impact of design and process (with business and technology).

Manufacturing-Process: Procedures need to be defined to cope with the variables – will a one-size-fit all model work?. Need to look at other industries re. their business models (not just efficiency over productivity, but also pre and post occupancy). Integration of suppliers into companies needed (and teams). Sustainable business models can be flexible (and tested business concepts can be added). Need to consider what to adopt and what not to adopt e.g. automation v non-automation (is there a happy medium?). Flexibility needed (variable product line).

Construction-Process: Important to consider new business models – which ones?, what remit e.g. house builders, SME's etc. (more than 100 systems and >500 suppliers). How can integration be achieved? (through RFID, BIM etc?). Performance of process - hard data needed (CBA etc). Interfaces between OSP and manufacturing (need to have the right skills?). ISCS report on the future of house building. Emphasis on onsite or offsite construction? Flexibility needed with elements of standardisation (economies of scale).

Design-Technology: Technology embedded in the product (in the factory); technology underpinning the business process; e-readiness of organisations (and the supply chain) – holistic implications on the business; BIM for offsite (product and process) – potential to exploit.

Manufacturing-Technology: Justifiable automation - how much is enough? (optimisation, business case, payback period etc); product and process design – DfM (software and systems development, DSS, integrated product delivery etc); supply chain management – MRP and ERP expensive (inflexible and somewhat limited); modelling and simulation – training needed (systems analysis, discreet event simulation and modelling etc).

Construction-Technology: There is a need to understand what information is created, used and exchanged (Product Modelling Ontology, W3C etc) - common tools from different vendors (integration and interaction); BAE/BAA/IBM systems approach. Granularity of product data could be used better - detailed information e.g. installation, storage, size, mass, lifting requirements, health and safety issues etc. (BIM is important here). Risk needs to be understood more e.g. i) existing product/process in established application areas, ii) existing product/process in new application areas, iii) new product/process in established application areas, or iv) new product/process in new application areas [as all carry different risk].

Design-People: Traditional versus non-traditional - new ways of working require new skills (especially product modelling.), new thinking, greater collaboration, reassessment of discipline areas, change in individual and company behaviour. OJT and learning needed (industry and academia collaboration). New approach needed to design (key USPs need to be sold re suppliers, assemblers, transport operations etc.) DfMA is an important part of this, along with logistic integration into the design process. Product catalogues, smart connections etc are available.

Manufacturing-People: Mistakes are not openly acknowledged. Multi-disciplinary or interdisciplinary? Mind-set training needed (look at projects rather than products). Decisions have to be modelled in an integrated way (incorporating risk etc.) Shop floor approach needs to change and benefits need to be made clear. Link to disaster management?.Mass customisation – service parts (how to address the various markets). Job roles and functions need re-defining. Integrating people into future scenarios.

Construction-People: Up-skilling of personnel i), so that existing site labour or new trainees can work in the production factory; ii) so that employees know how to install pre-fabricated products and modules on site (this would require training/investment). Healthy and comfortable working conditions could be a key USP (Health and Safety, better working environment, standardised production system etc). Sustainability - social benefits, continuity of employment, economic - stable and long term employment, transportation - pick zones (reduced emissions etc). Productivity - greater efficiency and productivity, no weather disruptions etc. New workforce – greater attraction because of better working conditions, resolution of unskilled labour, no age limit or pre-requisite skills for entering the sector. Perhaps adopt the triple bottom line approach.

Discussion

The findings presented in this paper in many ways reflect the long-term vision needed by a range of stakeholders noted in extant literature. These are however in some respect governed by changes in legislation (which more often than not require more immediate solutions) to prepare the industry for the future, once the market stabilises. From a design approach, the key message is that emphasis should be placed on flexibility (to design out obsolescence), as this reinforces the business case for OSM. Moreover, as OSM can openly demonstrate a much wider range of solution than had previously been made available to the client (customer), there is a correspondingly higher need to understand the requirements of the occupants to design accordingly. Given this, improvements are needed to current business models to reflect the changing requirements of clients and new processes involved. As there are a number of new SMART components and connector pervading the market, increased options with improved flexibility solutions are now available. However, these will need to be integrated. This might for example include creating (or implementing) specific aspects of the manufacturing user-case business models. In addition, new relationships with the supply chain will need to be fostered and developed. This may involve new procurement routes and contractual agreements, or new production schedules which maximise efficiency, productivity, and logistics. Increased standardisation of products from different sources should also be explored further (e.g. British Standards, EU Standards, International Standards), as this would significantly improve interchangeability from any number of suppliers whilst increasing product selection and market diversification. This would allow different user scenarios to be developed for various typologies (design variations). These holistic issues and interconnectivity can be seen in Figure 3.

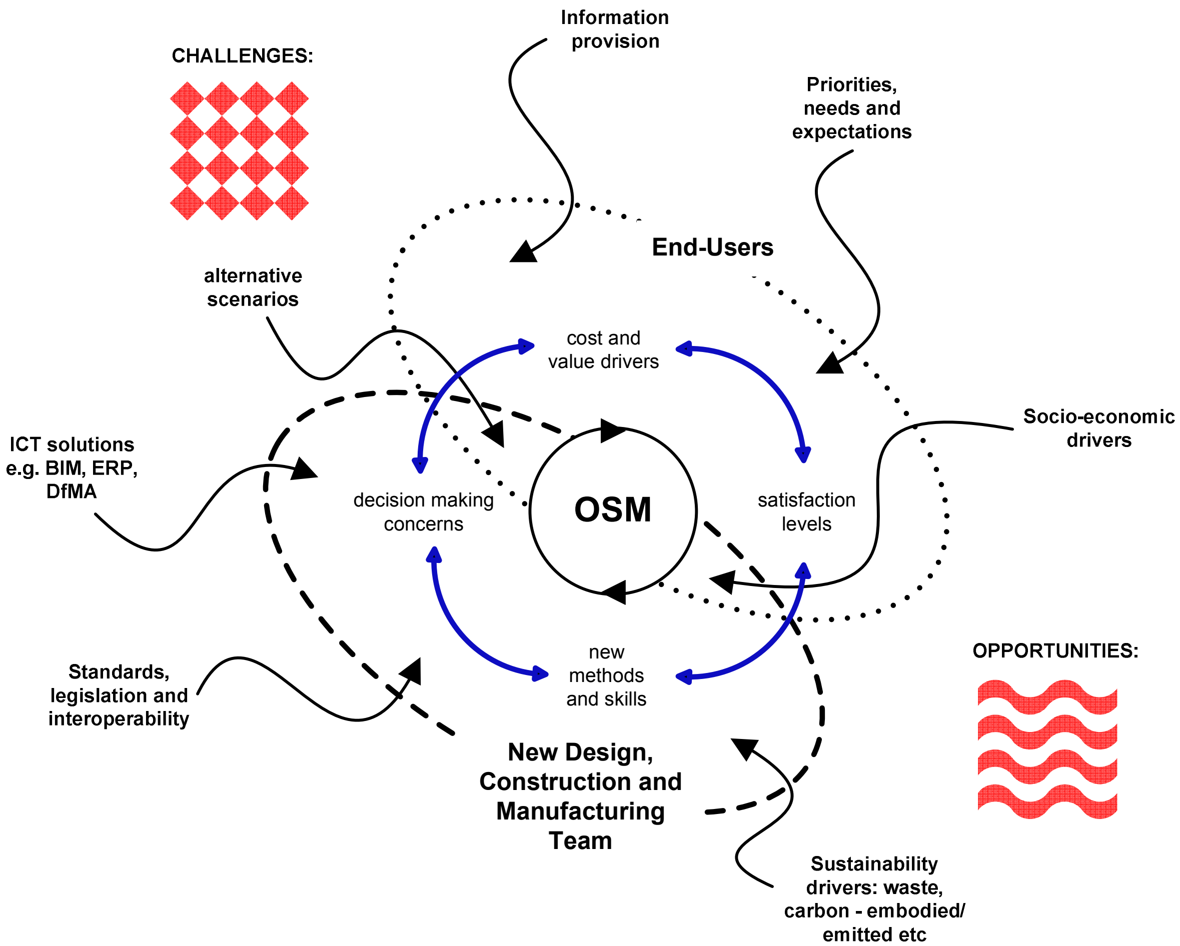

Figure 3: OSM Interrelationship Model

Conclusion

Offsite manufacturing has been on the agenda for quite a while now. It has been offered as a potential solution across a number of areas, not least the 'green agenda' aligned to sustainable construction, but also improved delivery times, higher integration opportunities, improved quality, reduced costs etc. A number of significant and prominent key reports have been produced promoting 'ways forward'. This research presented an illustration of the potential to integrate design, development and delivery of products and services using offsite construction as an exemplar. The research methodological approach included three discursive on-line webinars with domain experts to collect primary data, followed by one workshop to validate findings. Research findings identified the links between nine areas: *Design-Process*: *Manufacturing-Process:* *Construction-Process*: *Design-Technology*: *Manufacturing-Technology*: *Construction-Technology:* *Design-People*: *Manufacturing-People*: and Construction-People. Research limitations are therefore bounded by this data set. Whilst the interconnectivity of these nine areas provided some meaningful outcomes (especially through the strength of connections and level of granularity of detail provided), one of the main findings that needs to be emphasised is the increased need to provide information 'transparency' in order to fully maximise and exploit offsite manufacturing technologies and processes (as this can enhance the collaborative working practices of the disparate stakeholders involved). Similarly, it is advocated that new employee skill sets which embrace an 'open system' philosophy are needed to drive forward innovative solutions. There is also a need to 'sell' the emerging benefits of offsite manufacturing technologies and processes to these stakeholders. Pivotal to this is the need to create a new culture of OSM/DfMA; from the initial outline design stage, through to the development of the project team, the design and tender process, and full engagement of all stakeholders involved.

References

Akintoye, A., Goulding J.S, and Zawdie, G., (2012), Construction Innovation and Process Improvement, Wiley-Blackwell, UK

Buildoffsite (2012), http://www.buildoffsite.com/downloads_publications.htm#mod [accessed February, 2013]

Cera, C.D., Regli, W.C., Braude, I., Shapirstein, Y., and Foster C.V., (2002), "A Collaborative 3D Environment for Authoring Design Semantics", IEEE Computer Graphics and Applications, Vol. **22** (3), pp. 43-55.

CIDB, (2011), Industrialised Building Systems Roadmap 2011-2015, CIDB, Malaysia, http://www.ibscentre.com.my/index.php?option=com_content&view=article&id=48&Itemid=106&lang=en&language=eng [accessed February, 2013]

Cresswell, J.W., (2009). Research Design. Qualitative, Quantitative and Mixed Method Approaches (3rd edition). California: Sage Publications Inc.

Davenport, T.H., (1992), Process Innovation: Reengineering Work Through Information Technology, Harvard Business School Press, Boston, Massachusetts, USA

Davis Langdon, (2011), Cost Model: Off-site Manufacturing, http://www.davislangdon.com/upload/StaticFiles/EME%20Publications/CostModels/DL-Specialist%20Costs_Off-site%20Manufacturing%20Sept11.pdf [accessed February, 2013]

Egan, J., (1998), The Egan Report - Rethinking Construction, Report of the Construction Industry Taskforce to the Deputy Prime Minister, 1998, London: HSMO.

Fruchter, R., Pena-Mora, F., and Roddis, W.M.K., (2000), Computing in Civil and Building Engineering, Proceedings of the Eighth International Conference (ICCCBE-VIII), August 14-16, 2000, Stanford University, American Society of Civil Engineers, New York, USA.

Gann, D.E., (1996), Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan. Construction Management and Economics, 1996. **14**(1): p. 437-450.

Gibb, A., and Pendlebury, M., (2006), Glossary of Terms, Buildoffsite: Promoting Construction Offsite, http://www.buildoffsite.com/pdf/BuildoffsiteglossaryV1.3revised_july06.pdf [accessed February, 2013]

Goulding, J., Nadim, W., Petridis, P., Alshawi, M., (2012), Construction Industry Offsite Production: A Virtual Reality Interactive Training Environment Prototype, Advanced Engineering Informatics, Volume **26**, Issue 1, January 2012, pp 103-116

Gu, N., and London, K., (2010), Understanding and facilitating BIM adoption in the AEC industry, Automation in Construction, Vol. **19**, Iss. 8, December 2010, pp. 988–999

HAC (2011)., Preserving Affordable Manufactured Home Communities in Rural America: A Case Study: Housing Assistance Council Press.

Hampson, K.D. and Brandon, P., (2004), Construction 2020 - A vision for Australia's Property and Construction Industry. 2004, Queensland University of Technology, Cooperative Research Centre for Construction Innovation for Icon., Net Pty. Ltd, Brisbane, Queensland, Australia

ManuBuild (2009), http://www.manubuild.net [accessed February, 2013]

Morgan, D.L., (1997), Focus Groups as Qualitative Research, Sage Publications, Inc; 2nd revised edition, London, UK

Mullens, M.A., and Arif, M., (2006), Structural Insulated Panel: Impact on the Residential Construction Process. Journal of Construction Engineering and Management (ASCE), 2006. **132**(7): p. 786-794.

Nadim, W., and Goulding, J.S., (2011), Offsite Production: A Model for Building Down Barriers: A European Construction Industry Perspective, Journal of Engineering, Construction and Architectural Management, Vol. **18**, No. 1., pp. 82-101

ONS, 2012, Office for National Statistics, http://www.statistics.gov.uk/hub/business-energy/production-industries/building-and-construction [accessed February, 2013]

Parker, A., and Tritter, J., (2006), Focus group method and methodology: current practice and recent debate. International Journal of Research and Method in Education, 2006, Vol. **29**(1): pp. 23-37.

Quicklockpartitions (2012), http://www.quicklockpartitions.com.au/ [accessed February, 2013]

Schuler, A., (2003), The Factory Built Components Industry Is Almost As Large as the Softwood Lumber Industry, in Structural Building Components Magazine. 2003.

Taylor, M.D., (2010). A definition and valuation of the UK offsite construction sector. Construction Management and Economics, **28**(8), 885-896.