Towards an Information System Representation of off Site Manufacturing (OSM) in Facilitating the Virtual Prototyping of Housing Design

Hanibal Abosoad¹, Jason Underwood¹, and Salhe Boreny²

¹School of the Built Environment, University of Salford, Salford M5 4WT, UK
²Academy of Graduate Studies, Tripoli, Libya

E-mail: hanibal.abo@gmail.com; j.underwood@salford.ac.uk; syboreny@yahoo.com

Abstract:
Major clients including the British Government have been encouraging the utilisation and application of Standardisation and Modularization (S&M) of Offsite Manufacturing (OSM) techniques for some time now. OSM is currently rapidly evolving resulting in the emergence of an overwhelmingly large number of innovative materials, components, systems, technologies, and methods. However, there is no systematic way for potential users to access this information and knowledge in a manner that can allow them to explore many alternative housing options that meet a wide variety of choices and to select the optimal options. The work presented in this paper is part of a research project aimed at developing a systematic approach for the computerised representation of this information and knowledge in a form that supports the virtual prototyping of housing design. This paper presents a systematic literature review on emerging systems, technologies and methods in OSM. An analysis of the literature which led to the development of a comprehensive classification system for representing OSM information is discussed. Ongoing work being undertaken to develop an information and knowledge repository to support a virtual prototyping environment for housing will also be presented.

Keywords: Offsite manufacturing, manufactured housing systems, classification system, virtual prototyping.

1 Introduction

There are pressures and high demands amongst the factors that led to the birth of OSM. This has/is continuing with the desire for the quality of housing being the driver. The only way forward in order to meet this demand is through the pursuit of OSM (Egan, 1998). This demand for new houses has greatly benefited the house building industry, which has implemented and used several design and construction improvements to keep up with the tremendous need for new homes around the world. Certainly standardisation
is not a new concept to the manufactured housing industry. Standardisation of measurements and component interfaces within housing is a key theme, because it enables easier replacement of technology in houses along with more rapid implementation of emerging systems. However, it is believed that standardisation in the construction industry may not be applicable as building parts vary and are not unique as in the motor industry for example. Japan offers the best example of recent experiments with the variety of types of traditional and industrialised house building techniques. The Japanese market is substantially large and quite different from that in the UK (Bottom, et al, 1996). Recently, there has been an increase in performance standards and requirements as found in the recent changes in the UK building regulations which have lead to the emergence of large a number of innovative materials, components, systems, technologies, and methods to meet criteria set by these recent changes. However, there is currently no systematic way for potential users to access the information and knowledge in a manner that can allow them to explore many alternative housing options that meet a wide variety of choices and to select the best option. The aim of the research presented is to develop a systematised approach facilitated through a virtual prototyping environment. The rational of this research is captured from the fact that the knowledge of OSM is still not yet systematised, which makes it difficult for both clients and all stakeholders in the UK construction industry and around the world to be able to make appropriate choices of construction methods. The research therefore aims to develop a systematic approach for the computerised representation of this information and knowledge in a form that supports and facilitates the virtual prototyping of housing design.

2 Overview

2.1 Definitions and Terminology

The purpose of this review section is to introduce unification and to illustrate the concept of offsite manufacturing and the related terminologies as well as the definition of virtual prototyping. A superficial history of OSM has also been reviewed to establish the existence and origin of such a concept and why it was necessary at the time of inception. The driver for such a concept which emerged during the World Wars was principally in response to the housing shortage and is still in existence today.

Today, there are high pressure demands for housing in numbers and quality which led to the birth of OSM. The only way forward in order to meet this demand is to pursue OSM (Egan, 1998). Currently, as well as historically, the problem of housing is not only the shortage of accommodation, but is also concerned with the quality, finish and the impersonal character of the dwelling units that are in disrepair (Malpass and Murie, 1994). The Construction Industry Training Board estimates that the industry needs 88,000 recruits every year for the next five years (Burwood and Jess, 2005). This skills shortage will be exacerbated by the increased levels of construction outlined in the Sustainable Communities Plan and prestigious large-scale developments, such as the 2012 Olympics, which will absorb significant manpower resources. Furthermore, the housing supply in the UK presently stands at 175,000 per annum and yet the demand stands at 230,000 per annum (Postnote, 2003). These are some of the issues that were identified in the early stages of the research that led to present the research being pursued.
Before going any further, it is important to define and understand all terms related to manufacturing housing. There is currently a proliferation of terms associated with Modern Methods of Construction (MMC) in practice. Ross and Richardson (2005) state that “there is no precise or universally agreed definition of what constitute modern methods”. MMC is defined in The Post Note from the Parliamentary Office of Science and Technology (2003) as “the manufacture of house parts off-site in a specially designed factory”. Therefore it is important to understand the relationships between MMC and OSM. Figure 1 illustrates the relations related to MMC. There is no doubt that OSM is the heart of MMC and of course MMC is not a new phenomenon. As depicted in Figure 1, MMC is the master key for all OSM, On-site Manufacturing and Traditional Construction, which mates' main focus on this research is OSM. Many have previously sought to define Off-site Manufacturing (OSM) or to use other terms to describe the basic principles behind it. Some have used the term OSM, while others have used the term of Off-site Fabrication (OSF). BURA (2005) describe OSM as “the part of the production process that is carried away from the building site in factory conditions”. Another clear definition for OSM is the “description of the spectrum of applications where buildings, structures or parts thereof which are manufactured and assembled remote from the building site prior to installation in their final position” (Gibb and Goodier, 2005).

![Diagram of MMC relationships]

Figure 1 Source relations related to MMC: BURA Report 2005.

2.2 Virtual Prototyping and computer application tool

Over the years, since the initial emergence of computer aided design (CAD) in the 70s, the emergence of Information and Communication Technology (ICT) has rapidly revolutionised and transformed the construction industry. Brandon and Hampson (2004) considered that virtual prototyping (VP) would have the highest likelihood of becoming the basis for design, procurement and asset management in the next 5 to 10 years, which provide the opportunity to try and exercise the design. Virtual prototyping is an electronic representation to facilitate all relevant decisions which can be made and the procurement processes can develop. Virtual prototyping in software development is rudimentary working models of a product or information system, usually built for demonstration purposes or as part of the development process. As defined by Wang (2002). “virtual prototype is a computer simulation of a physical product that can be presented, analyzed, and tested from concerned product life-cycle aspects such as design/engineering, manufacturing, service, and recycling as if on a real physical model. The construction and testing of a virtual prototype is called virtual prototyping”. Currently virtual prototyping technology is available but not sufficiently integrated.
OSM and VP should become sufficiently integrated by encourage more users.

Design environment software such as CATIA (Computer-Assisted Three-Dimensional Interactive Application) has improved the development among different products around a visual prototype. CATIA, which has been adopted for this research, is widely used throughout the engineering industry, especially in the automotive and aerospace sectors in where it equates to approximately 70% of the market. Many companies within the construction industry are also using CATIA in the form of Digital Project which has been adapted from the aerospace and automotive industry for the purpose of the construction industry. OSM processes are assembled by standard components same as aerospace and automotive industry. This software has been adapted by the famous architect Frank Gehry who is renowned for producing a string of exciting and unique designs including the Guggenheim Museum in Bilbao and the Walt Disney Concert Hall in Los Angeles. Frank Gehry works through a number of phases which include drawing, analysing function, sculpturing, determining needs and experimenting with new materials in complex buildings. The design process defies normal conventional design and the complexity of the product requires new methods of representation and manufacture. This is particularly so with regard to future planning and alteration of the finished product (Brandon, 2004).

2.3 Systems categorisation of OSM

Just as there are slight differences in the definition of OSM so there are different classifications. Off-site manufacturing can be classified in various ways and may involve key services such as plumbing, electricity, and so on. In addition, it can also be classified by material, such as timber, steel, concrete and masonry (Burwood and Jess, 2005). OSM classification system is supporting the VP approach to develop the base of the systemised knowledge and information of SOM. This section examines and reviews a number of different existing classifications including Wallace W Williams (Modular Classification), Gibb (Types of Pre-fabrication), Housing Corporation Construction and Keith Ross’s Classification. Different authors provide different explanations for each categorisation. The review covers all categories in off-site manufacturing classifications including descriptions for each. Table 1 compares the different views (terminologies) of the classifications that have been identified for off-site manufacturing. As shown, each of these sources uses different terms for the classifications. Table 2 shows the relationship between the authors’ classifications systems and the categories.
Table 1. Comparison of off-site manufacturing classifications

<table>
<thead>
<tr>
<th>Williams’s Modular Classification</th>
<th>Gibb Classification</th>
<th>Housing Corporation Classification</th>
<th>Keith Ross classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modular volumetric building</td>
<td>Volumetric off-site fabrication</td>
<td>Off-site manufactured – Volumetric</td>
<td>Volumetric construction</td>
</tr>
<tr>
<td>Modular Hybrid-volumetric building</td>
<td>Non-volumetric off-site fabrication</td>
<td>Off-site manufactured – Hybrid</td>
<td>Panellised systems</td>
</tr>
<tr>
<td>Modular system building</td>
<td>Component subassembly</td>
<td>Off-site manufactured – Panellised</td>
<td>Hybrid construction</td>
</tr>
<tr>
<td>Modular elemental building</td>
<td>Modular building or Whole building</td>
<td>off-site manufactured – Sub-assemblies and components</td>
<td>Sub-assemblies and components</td>
</tr>
<tr>
<td>Modular timber building</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modular pre-fabrication/component building</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: the relationship between the authors and the categories

<table>
<thead>
<tr>
<th>OSM Categories</th>
<th>Williams</th>
<th>Gibb</th>
<th>Housing Corporation</th>
<th>Keith Ross</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volumetric systems</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Hybrid systems</td>
<td>✓</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Panellised systems</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Sub-assemblies and component systems</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Modular (whole house) systems</td>
<td></td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

Table 3 presents the analysis and conclusion from Tables 1 and 2. At this section classification terms are studied and analysed in order to establish a new and comprehensive OSM classification. This new classification comprises all the clear definitions (systems) of off-site manufacturing. For example, Gibb classification includes the modular systems (whole house) which are not included by the other authors, therefore another larger classification with five categories has emerged. These categories are volumetric, panellised, hybrid, sub-assemblies and components, and Modular (whole house) systems.
Table 3. A broader new OSM classification

<table>
<thead>
<tr>
<th>OSM Categories</th>
<th>New classification</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volumetric systems</td>
<td>✓</td>
<td>Prefabricated building components in Pods</td>
</tr>
<tr>
<td>Panellised systems</td>
<td>✓</td>
<td>Prefabricated components in planes or panels</td>
</tr>
<tr>
<td>Hybrid systems</td>
<td>✓</td>
<td>Combination of Volumetric and Panelised</td>
</tr>
<tr>
<td>Sub-assemblies and component systems</td>
<td>✓</td>
<td>Simplified components like doors and windows manufactured in factories</td>
</tr>
<tr>
<td>Modular (whole house) systems</td>
<td>✓</td>
<td>Whole buildings manufactured in the factory. it could entirely be volumetric or penalised or both.</td>
</tr>
</tbody>
</table>

The perspective stems from the fact that knowledge of OSM, is still not yet systematised, making it difficult for clients and all stakeholders in the UK construction industry to be able to make appropriate choices of construction methods. And considering the fact that they had been too many controversies on what constitutes OSM, the debate seems to have split over to the various categorisation of OSM. To this end, different OSM categorisation from different authors have been analysed leading to a final superset category having been generated. This new OSM classification has been developed from authors to provide a comprehensive classification, which includes all the identified OSM categories to be use in VP environment.

2.4 Types of OSM systems presented in virtual prototyping.

OSM (building) systems can use a number of different materials or combinations of materials which can be volumetric, panel or hybrid. A building system is defined as ‘all work components necessary for a particular type of building together with their execution procedures and techniques’ (Warszwaski, 1990). They can be grouped according to method of production, degree of pre-fabrication and structural principles used materials, weight and methods of assembling structural elements, application to different building types, and flexibility of design and their varying permutations. The different systems also take into consideration structural and innovative aspects, e.g. it would be illogical to manufacture a modular building using concrete that has to be transported over a long distance. All systems (panellized, volumetric, hybrid, modular and sub-assembly and components) are explained based on their materials as follows. These systems are presented in a virtual library, to organise the knowledge and information of OSM (see figure 2). These systems are the base/the foundation to present the knowledge and information of the OSM.
3 Research Methodology

This study will adopt three methodologies: Literature review, the data collection techniques and the virtual prototyping methodology. As the focus of this research is technical and aims to demonstrate the use of basic OSM concepts in a virtual prototype environment, the main research contribution is geared towards the technical side (solution) for OSM process by demonstrating some VP moulds.

Literature review: To understand the knowledge and definition of OSM and establish the new comprehensive OSM classification system and comparing between computers aided design software to choose the software (CATIA) to apply the in virtual prototyping environment. In other word, Studying and understanding the classification systems of OSM; including materials of the systems and the process of OSM techniques in order to produce the initial functional and specification of the OSM systems to apply it in a prototyping environment.

Data collection techniques: These techniques are adopted in order to collect the relevant state-of-the-art information and knowledge on OSM, which aims to capture this data from exhibitions (i.e. Offsite2005 and Interbuild2006) and by referring to company (product manufactures) catalogues/brochures. Initially, the planned strategy was to adopt a qualitative approach that aimed to collect the relevant data and knowledge from the exhibitions via interviews/surveys with the product manufacturers, and so on. However, due to the large number of companies, the logistics (timeframe at the exhibitions, only non-technical sales people being present at the stalls, and so on) and much of the product knowledge and information being captured within manufacturers’ brochures, the qualitative approach strategy was abandoned (for this purpose). Furthermore, many sources such as internet books and periodicals were used to collate the relevant information and knowledge for OSM for housing design. On the other hand, it is proposed to adopt a qualitative approach to enable the elicitation of the
relevant knowledge (such as material, sizes, process, and so on) from and OSM housing designers in support of the virtual prototyping methodology.

Virtual prototyping methodology: this is the core methodology. It facilitates to understand the concept of any project system. Lantz (1986) defines prototyping methodology as “an information system development methodology based on building and using a model of a system for designing, implementing, testing, and installing the final system”. Furthermore, Lantz (1987) elaborates on his theory of prototyping methodology by stating that “prototyping is about people”. Understandably, this falls in line with the consequential rationale and hence objectives of current research. Prototyping enables to “see” a system, “play” with it and “modify” it before it is implemented (Lantz, 1987). Based on this, a methodology will concentrates on the virtual prototyping of prefabricated housing design, which facilitates and correlates different manufacturing processes as well as construction techniques.

The virtual prototyping is being developed based on the comprehensive classification systems of the OSM process previously described through four stages:

Study and understand the classification systems of OSM: this includes materials of the systems and the parts of OSM housing in order to produce the initial functional and specification of the OSM systems and apply it in a prototyping environment, i.e. prototyping libraries. The prototyping libraries are classified into two libraries; materials and OSM (see section 5).

Produce and implement different technical solutions to standard components: four major (CATIA v5) technologies/functionalities (design table, formulas, power-copy and assembly concentrate) are produced to demonstrate the technical approaches such as flexibility to change parameters and less repetition for the users. Furthermore, the knowledge tree for each model organises geometric information for each part of the OSM housing and presents the properties for the materials.

Develop a systematic approach that supports the virtual prototyping of housing design: through multi-case-studies, a systematic approach that facilitates the process of OSM techniques will be established for potential users to access the computerised representation of the information and knowledge (captured from literature) in a manner that can allow exploration of many alterative housing design options that meet a wide variety of choices. These multi-case-studies will be available as libraries in order to select alternative choices in one package.

Testing and validation of the virtual prototyping system: further developing the solution to achieve optimum modelling through user feedback in order to assess the virtual prototyping environment for housing design. This feedback will be captured through a combination of semi-structured interviews and questionnaires.

4 Virtual prototyping representation based on offsite manufacturing knowledge.

This section presents the on-going study being undertaken to develop a VP environment for OSM housing design. Having established a comprehensive classification system, the development and implementation of the two libraries (materials and OSM) within the virtual prototyping environment towards developing a systematic approach that supports
and facilitates the virtual prototyping of housing design are explained. These two libraries are linked by borrow the OSM library from materials library to multi choices to select construction materials. An additional, the OSM Library discriminated with geometry drawing for the systemised classification of OSM (see figure 2).

A virtual prototype is defined as a computer based simulation of a prototype system or subsystem with a degree of functional realism that is comparable to a physical prototype (Haug, Kuhl, Tsai, 1993). Virtual prototyping means the process of using virtual prototypes instead of or in combination with physical prototypes, for innovation, test and evaluation of OSM design, process techniques and materials.

4.1 Materials library

In this section a materials library for construction materials is introduced to complement the available OSM library. This library is classified into five categories; based on the new and comprehensive OSM classification described previously, i.e. architectural facade systems insulated panel systems, ventilated facade systems and conventional construction facade systems. A large number of materials are presented and specified in order to give more value to users. These materials have been chosen from companies’ brochures which have been collected from both exhibitions (Offsite2005 and Interbuild2006) and Internet. As an example the library materials shown in Figure 3 is mostly used for façade systems and insulated panels. A materials library is adding new value to the software CATIA, by providing more choice to the library.

Figure 3. Illustration of the library for Façade and Insulated Panel materials.

4.2 Standardised components and measurement.

Components and Measurement standardisation is an effort to achieve product and system commonality to simplify the installation and replacement of building components and building systems, and to improve compatibility with other building systems. Standardisation of components and dimensions or measurement in CATIA is a powerful tool that can promote various degrees of customisation by facilitating design
alternatives with a structure. Figure 5 shows an example of Structural Insulated Panels (SIPs), which consist of two outer skins and an inner core of an insulating material to form a monolithic unit. Most structural panels use either plywood or Oriented Strand Board (OSB) for their facings. OSB is the principle facing material because it is available in large sizes (up to 4m x 11m sheets). Many manufacturers maintain a standard panel for ease of transportation and handling. SIP walls that are 12cm thick or 18cm thick, are the standards that are most used in SIP manufactures in the UK. The floor systems used in a SIP system are integral to the structural system. The standard joist floor which may also be referred to as an I-Beam or I-Joist because of it is T shape in cross section is used as standard dimensions. Also the foundations are precast concrete with standard dimensions. All building components are given the correct standard dimensions by using a design table and power copy and the components are assembled in the construction site by using constraint objects. In addition to the visual model, in a powerful tool such as Digital Project the modular work is also represented in a Specification Tree as shown in Figure 4. This example has been selected from the classified OSM library. The rest of the systems are under development through the PhD research study by developing more standardised models of systems after designing, implementing, testing, and installing the final system. In addition, the materials library complements the OSM library in that it enables materials to be selected from the materials library along with the required properties for each part of the component.

Figure 4. Structural Insulted Panels (SIPs) system assembled on site

5 Conclusion and Further Research

The OSM of housing systems refers to forms of construction undertaken in a factory rather than on a building site. Buildings are manufactured as kit-of-parts or complete product assembly. The work presented in this paper is part of a research study that is focused on the development of an information system that facilitates the VP for the OSM of housing design. Part of the literature review is definitions & terminology of OSM and computer application tool presented in VP. Considering the fact that there had
been many controversies on OSM classifications, a comprehensive new classification is presented. A part of the virtual prototyping libraries are presented in the form of two libraries, which have been developed and implement within CATIA i.e. materials and standard components and measurement libraries. These libraries are just part of a work aimed at developing a systematic way for potential users to access this information and knowledge in a manner that can allow exploring many alternative housing options that meet a wide variety of options. Future work towards achieving the aim of the research will be to further develop the systematic information of OSM housing design in the virtual prototyping environment through the development of more components that can save time for the users, while providing more options (manufacturer’s components) to select for OSM design. The process of OSM techniques will be further studied in order to align the virtual prototyping environment with the practice of OSM housing design. Finally, the virtual prototyping environment will be tested and validated with industry OSM designers to assess the applicability of the approach.

6 References

John Egan, (1998), Rethinking Construction: The report of the construction task force to the Deputy Prime Minister, John Prescott, on the scope for improving the quality and efficiency of UK construction.
Lewicki and Bohdan, (1966), Building with large prefabricates / translated from the Polish by Express Translation Service. Elsevier.