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TYPOLOGIES OF OFFSITE CONSTRUCTION

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ABSTRACT

In the 21st century, where smart and modern technologies are developed at an expeditious rate, construction industry has survived over centuries, despite its slow rate of technology adaptations, poor productivity, lower sustainability and vastly reported skill shortage. Technological advancement is the catalyst to solve these issues attaching extreme significance to transform the construction industry in line with industrialisation, digitalisation and globalisation. Sequential industrial revolutions have evolved to the present day's Fourth Industrial Revolution which is also known as Industry 4.0, under which offsite construction leads to the reduction of onsite labour intensity and shift the tasks to factory based manufacturing paradigms. Study on offsite construction revealed different types of offsite construction available in literature; none of which specified a logical method of offsite construction types development to suit the current technology advancements in the global construction arena. Available literature rather mention types of offsite construction based on examples and not the construction technology or combination of onsite to offsite work component. Therefore, this research was carried out to develop typologies of offsite construction using 10 available types of offsite construction. Literature was analysed using content analysis method through the NVivo 2012 (QSR) computer software. Findings revealed six typologies of offsite construction with incrementing portions of offsite construction in the order of; Components, Panels, Pods, Modules, Complete buildings and Flat pack. Therefore, this research contributes to knowledge by the development of typologies of offsite construction through a scientific approach while addressing the 21st century technology advancements available in the construction industry worldwide.

Keywords: *Offsite Construction; Technology Development; Typologies.*

1. INTRODUCTION

There is a large volume of published studies on Offsite Construction (OSC), which allows to gather a plethora of knowledge (Abanda, *et al*., 2017). OSC is manufacturing and assembly of building elements, components and modules within a factory to be transported onsite for installation (Arif and Egbu, 2010), which is visible in any construction project in varying degrees. There are different types of OSC such as pre-finished manufactured products (doors, windows, light fittings), panelised walls, pre-furnished modules and the like (Steinhardt and Manley, 2016). However, an arguable

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weakness in OSC research is the unavailability of a valid typology of OSC representing different mixes of onsite and offsite combinations. Therefore, this research aims to develop typologies of OSC by evaluating the available secondary sources of literature.

There are 5 objectives to be achieved for the whole study, "Developing a skill profile prediction model for typologies of offsite construction", out of which this paper indicates the realisation of the first objective by developing typologies of OSC. Developed typologies establish the different mixes of onsite and offsite construction combinations to be applied in the later stages of the research in achieving the remaining 4 objectives. They are *(a) to classify skill profiles required for typologies of offsite construction*; because substantial varieties of skills used in different typologies of OSC projects need to be classified to countable categories. Next objective is *(b) to develop a conceptual model that embeds the skill profile classifications and typologies of OSC.* The developed conceptual model is used *(c) to develop a detail model incorporating different types of buildings in various predominant materials such as concrete, timber and steel.* This objective is to be achieved using data simulation modelling technique, in order to predict the future skill requirements for different typologies of OSC. The final objective is *(d) to test, validate and develop a prototype system that helps the prediction of onsite and offsite skill requirements*.

2. LITERATURE REVIEW

2.1 WHAT IS OFFSITE CONSTRUCTION?

Traditional construction is the onsite erection of buildings with the involvement of cast in-situ reinforced concrete and delivery of materials to be used in a step by step onsite construction process opposed to the factory manufacturing and site assembly of buildings under OSC (Abanda, *et al*., 2017). Current state of OSC will be largely affected in the future due to industrialisation and the increasing shift of previously onsite construction activities to offsite factory-based prefabrication (Ginigaddara, *et al*., 2019). Hence onsite works will be minimal and only focussed on the assembly of buildings or building components performed by advanced self-directed work package gangs (Goulding, *et al*., 2014). In this regard, mix of onsite to offsite combination varies depending on the type of OSC carried out in the particular construction project. Similarly, depending on the type of OSC, requirement for skilled workers and professionals both onsite and offsite changes (Southern, 2016).

A typology is different to basic types as a type is a group of items with shared features while a typology is a systematic classification of types, analysed through a scientific notion (Jacoby, 2016). Hence, this research will develop the typologies of OSC, based on previously developed types of OSC in literature.

2.2 AVAILABLE TYPES OF OFFSITE CONSTRUCTION

There are many literature findings on different types of OSC based on the amount of onsite and offsite work carried out. These classifications establish severe resemblances as a result of the influence by literature of Gibb (2001). Next, different types of OSC identified by different authors worldwide is tabulated in Table 1 mentioning the definitions and examples. Evaluation of these categorisations will lead to the development of typologies of OSC in order to explore the current practice in the industry.

Table 1: Available types of offsite construction

Author	Types	Term/Definition	Examples
Gibb (2001); Gibb and Isack (2003)	Component manufacture and sub-assembly	Small scale sub-assembly of construction project components and the items which are never considered to produce onsite	Door furniture, light fittings, windows
	Non-volumetric pre-assembly	Factory assembled prior to final positioning. Encompasses a major structural part of the project yet do not create usable space	Wall panels, pipework assemblies, structural sections, cladding panels
	Volumetric pre-assembly	Makes a closed unit within an independent structural frame	Plant-room, toilet pods, lift shafts
	Modular/ complete building	Similar to volumetric units, yet it is the entire project with usable space. External finishes are done on site	Retail outlets, offices, prisons, multi-storey residential units
POSTnote (2003)	Panels	Panels with mechanical services	Ready-made walls, roofs and floors
	Modules	Ready-made 'pods' pieces are fixed together to compile the building	Bathrooms, kitchens
Blismas *et al*. (2009)	Non volumetric pre-assembly		Precast concrete items and pipes, timber and steel wall panels
	Volumetric pre-assembly		Wet room modules
	Modular building		Schools, homes and shelters
Kempton (2010)	Site-based methods	Onsite construction activities which are not classified under OSC	Thin joint blockwork, glulam timber
	Sub-assemblies and components	Building component manufacturing which are inadequate to be called direct OSC, yet comes under OSC	Floor cassettes, roof cassettes, pre-assembled mechanical services
	Hybrid	Combination of panelised and volumetric, serviced and repeatable units	Bathrooms
	Panellised construction	Flat panel units; open and closed.	
	Volumetric construction	Modular or pod construction with from basic shells to fully fitted units.	Bathrooms, kitchens
Boyd *et al*. (2013)	Off-site preassembly	Producing building components, materials, and equipment.	Trusses, staircases, precast elements,
	Hybrid systems	Pods which are fully prefabricated buildings with completed finishes.	
	Panelised system	The use of pre-manufactured structural framing systems.	Doors, windows, cladding, timber frames
	Modular buildings	Pods accompanying several rooms including finishes and services.	Complete houses, apartment blocks

Author	Types	Term/Definition	Examples
Lawson *et al*. (2014)	Manufactured components	10% - 15% OSC in value terms	Precast elements, cladding panels
	Elemental/ planar systems	15% - 25% OSC in value terms	Panels, steel/ timber frames
	Modular and mixed construction systems	30% - 50% OSC in value terms	Plant rooms, modular lifts and stairs, podium levels, bathroom pods
	Complete building systems	60% - 70% OSC in value terms	Fully modular buildings
Steinhardt and Manley (2016)	Significant assemblies	These do not encompass space	Wall panels
	Non-structural volumetric		Bathroom pods
	Structural volumetric	Complete houses or enclosed modules	
Goh and Loosemore (2016)	Traditional building	Construction carried out by hand based on various crafts or trades	Installation of prefabricated components
	Onsite prefabricaiton	Assembly of building components onsite into the specific position	Handmade roof trusses, framing, façade
	Offsite prefabrication	Offsite assembly of building components	Roof trusses, air conditioning units
	Pods	Pre-assembled units that enclose space	Toilets, bathrooms
	Complete modular	Highest level of industrialisation with fully finished unit	Complete structure
Abanda *et al*. (2017)	Panellised	Flat panels which are assembled onsite to obtain the 3D structure	
	Volumetric	3D units which enclose usable space, yet do not encompass the building structure. These are also known as non-structural volumetric spaces.	Bathroom pods, plant rooms, lift shafts
	Hybrid	Combination of both volumetric and panellised systems.	
	Modular systems	Pre-assembled volumetric units with an onsite work component	Hotel modules
	Components and sub-assembly systems	Factory produced items which are not considered under full systems; yet become parts of the structure.	
Nguyen *et al*. (2018)	Manufactured components	Site intensive construction	
	Linear or 2D manufactured assemblies	Popular in 1950's and 1960's	
	3D volumetric modules	Major parts of the buildings being factory made in 1960's and 1970's	

Author	Types	Term/Definition	Examples
	Complete building systems/ Modular	Modules that are completed up to 70% offsite from the end of 20th century	

3. RESEARCH METHOD

Previous studies on OSC types are based on the industry usage and past theoretical data. It is surprising that all these types are formed without an overarching classification. Furthermore, none of the identified types of OSC have given considerations for the labour component of each type of OSC. Additionally, only 01 out of the 10 considered types (Lawson, *et al*., 2014) indicated onsite and offsite combination in each type of OSC in value terms of a construction project. However, this also lacks the predominant measures in how the percentage terms of onsite and offsite combination was developed.

A systematic literature review was conducted to identify researches or reports which include types of OSC with definitions and examples. A variety of journal articles, books, conference proceedings, reports, theses, the world wide web and other resources were referred to explore and understand the existing knowledge on types of OSC. Composition of the literature sources indicated in Table 1 has a majority of journal articles (7) and each one of conference proceedings, books and reports. Literature was evaluated by identifying themes, patterns and biases through content analysis which contributes for the development of the typologies of OSC.

Categorisations which did not provide proper definitions were removed from the study with the aim of obtaining higher validity in the findings. A qualitative approach was employed to obtain a more meaningful categorisation of typologies of OSC using NVivo 2012 (QSR) computer software, similar to the work of Nadim and Goulding (2011). This approach was also given consideration to obtain valid inference from the collected data which is in "text" format (Goulding, *et al*., 2014). Therefore, a content analysis was conducted for the data collected on available types of OSC indicated in Table 1 as it allows to systematically review literature in order to identify common themes and patterns (Steinhardt and Manley, 2016).

4. FINDINGS AND DISCUSSION

Nodes were created based on available types of OSC as shown in Figure 1.

Name	Files	References
Types of OSC	1	88
Volumetric pre-assembly	1	21
Site Based Methods of Construction	1	5
Non-volumetric pre-assembly	1	23
Modular building	1	17
Hybrid	1	4
Component manufacture and sub-assembly	1	18

Figure 1: Nodes created for available types of offsite construction

Findings disclose that there are six major typologies of OSC which have various relative considerations according to the number of references. Out of the four references for

hybrid construction, one example was given as "bathrooms" and the other three references signified the below definition.

> *"hybrid construction is combining panelised and volumetric offsite construction which is heavily used for repeatable units inclusive of panel technology"*

This definition seems to be incosistent simply due to the nature of the construction industry where combination of different materials, methods and processes (E.g.: labour and machine integration) is prominent. Hence the word "hybrid" can be substituted to any of the construction industry activities which makes it meaningless to be used as a typology of OSC. Arif and Egbu (2010) state that there is always possibility for adapting hybrid OSC which does not necessarily need to be a separate typology of OSC. Moreover, the less number of references for hybrid OSC in the collected data set also establishes the inappropriateness of using "hybrid" as a seperate typology. Hence it is confirmed that hybrid is not a typology of OSC and is rather a combination of two other types of OSC.

Site based construction identified in the content analysis refers to the "*traditional onsite activities which are not classified under OSC* (Kempton, 2010)". Provided definition is self-explanatory indicating that site based traditional construction is not a part of OSC and hence it proves to be incomparable with the typologies of OSC. On the contrary, it is observed that site based construction is evidenced in each typology of OSC in varying degrees depending on the amount of factory manufacturing and onsite construction occured. Therefore, it is confirmed that site based construction does not qualify to be considered as a typology of OSC and rather it is the opposite of OSC which is inevitable in any typology of OSC.

Additionally, almost all the materials which are used in construction processes such as bricks, blocks, steel, tiles, timber panels and the like are also either produced or treated in factory facilities. Similar to the exclusions made by Goodier and Gibb (2004) this material manufacturing procedure is excluded from typology development process in this research. Remaining major types of OSC are the same as what was initially introduced by Gibb (2001) almost 20 years before current technology advancements. There are different names provided for each of the types of OSC as shown in Figure 2.

Present findings seem to be consistent with industry practices especially relevant to the basic 02 types of OSC; i.e. (1) component manufacturing and sub-assembly and (2) non-volumetric pre-assembly. Sub-assembly of components refer to the breakdown of original assembly task to several smaller sub tasks while pre-assembly indicates the assembly of components offsite prior to transportation to the site (Gibb, 1999). Therefore, all OSC types are related to some proportion of both sub-assembly and pre-assembly activities which signifies the little use in including the terms in OSC typology. Hence, developed OSC typologies in this study do not incorporate the wordings "sub-assembly" and "pre-assembly" as it improves the logicality of the research.

4.1 COMPONENTS

Examples of component sub-assembly are doors, windows, ironmongery, and light fittings which are typically considered as non-structural building elements. Components are "*required in smaller scale, comprising up to 10 - 15% of project value, do not come under full systems yet becomes a part of the structure"*. Furthermore, components require delivery, storage and skilled assembly onsite (Taylor, 2009), which "*involves a significant amount of onsite construction prior to the final usage"*. Gibb and Isack (2003)

also signify that none of these components are to be constructed onsite under any circumstances.

Evaluation of the terms used to refer components reveal that manufacturing and sub-assembly are common terms used to differentiate the types of OSC by various authors. However, manufacturing is the basis of OSC which is common to any typology. Likewise, sub-assembly involves the step by step installation of elements to the building structure either onsite or offsite. This leads to the redundancy of both terms; manufacturing and sub-assembly to provide a clear and a focussed meaning. Hence **Components** can be considered as the basic typology of OSC which involves the minimal percentage of offsite production and the highest percentage of onsite fixing and installation.

Name	Files	References
Other Terms	1	26
Component manufacture and sub-assembly	1	6
Components and sub-assembly systems	1	1
Manufactured components	1	2
Offsite pre-assembly	1	1
Sub-assemblies and components	1	1
Traditional building	1	1
Modular or complete building	1	5
Complete building systems	1	2
Complete modular	1	1
Modular systems	1	1
Structural volumetric spaces	1	1
Non-volumetric pre assembly	1	8
Elemental or planar systems	1	1
Linear or 2D manufactured assemblies	1	1
Offsite prefabrication	1	1
Panelised construction	1	2
Panelised system	1	1
Panels	1	1
Significant assemblies	1	1
Volumetric pre-assembly	1	7
3D volumetric modules	1	1
Modular and mixed construction systems	1	1
Modules	1	1
Non-structural volumetric spaces	1	1
Pods	1	1
Volumetric construction	1	2

Figure 2: Other terms used for types of offsite construction

4.2 PANELS

Panels are structural elements such as walls, roofs, floors accompanied by mechanical services. These account for 15 - 25% of a project value and yet, do not create usable space. Panels rather create an enclosed structure onsite followed by the assembly and erection. There are several types of panels or panelised assembly as classified by (NHBC, 2006) such as open panels, closed panels, concrete panels, composite panels, structural insulated panels, infill panels and curtain walling. Each of these panels exhibit different features causing for the typology to be dispersed over various items. There are several other terms (Figure) referring to panels, all of which provide a similarity to components. It creates confusion with components as they are also non-volumetric, elemental, mostly 2D and linear. Moreover, content analysis reveals that 04 out of 08 references (50%) used terms similar to panels to denote a type of OSC. Hence, the term; **Panels**, is dominant among the others and can be identified as the second typology of OSC.

4.3 PODS

Third and the most profound typology of OSC is pods which is the *manufacturing of 3D structures to develop an enclosed unit* that are detachable and self-contained. Some authors complicate the term with volumetric and modular which means the collection of 3D elements to construct a more complex structure. Volumetric means accompanying volume or space and it is common to any typologies of OSC beyond panels. In order to avoid confusion, the term volumetric is abandoned from the OSC typology development procedure. Also, modules refer to far more complex and unique structures which are not necessarily repetitive as pods. Hence both these terms; volumetric and modular are overridden by the term "pod" due to the repetitive production of enclosed spaces to suit a definite purpose.

In a simpler notion, Lawson, *et al*. (2014) refer pods *as 04 sided enclosed structures that account for 30 - 50% of a construction project in value terms*. Examples are bathroom pods, kitchen pods, prison pods and plant room units. Pods are to be installed onsite within or onto an independent structural frame (Gibb, 2001). Hence this typology of OSC requires a heavy portion of skills for transporting the pods, handling and installing them onsite and offsite manufacturing along with fully furnished interior and mechanical services (Taylor, 2009). Similar to the views of Gibb (2001), Abanda, *et al*. (2017) also suggest that pods are non-structural. Interestingly, none of the other authors who introduced types of OSC do not indicate a strong implication on the structural capacity of pods. This is due to the small space coverage by an enclosed pod out of the entire building area. Based on the findings, it is confirmed that **Pods** are the third typology of OSC which is a non-structural, volumetric section of the building.

4.4 MODULES

Next level of advancement in typology of OSC is modules, which is also defined as the composition of the whole building in different modules. A module is a ready to use building element as it is manufactured offsite including complete fixtures and fittings (Pan, *et al*., 2008). Modules provide structural strength to the building and *up to 60 - 70% of construction project value happens offsite* (Lawson, *et al*., 2014). Conversely, a recent report by Prefab Logic (2019) on module construction in USA, shows how 90 - 95% of the building is completed within a factory including service installations. Similarly, modules shift 90% of project activities to factories (Johansson and Meiling, 2009).

Modules are not complete buildings and rather account for a portion of a complex structure. Entire usable space of the building is manufactured offsite as several different modules including internal finishes and mechanical services to be transported onsite, erected and complete external finishes (Gibb, 2001). This onsite assembly and erection only leads to the realisation of whole building which is why modular cannot be referred to as complete buildings. Retail outlets, office blocks, school buildings, multi storey residential units and apartment blocks are the examples of modular buildings, of which skills requirement for onsite assembly is limited to a 05 carpenter's group (Johansson and Meiling, 2009). Hence **Modules** are the fourth typology of OSC which encompasses the structure of the building.

4.5 COMPLETE BUILDINGS

This is the extension of modular buildings to the next level of OSC, where the entire building is manufactured offsite as a single unit and then transported onsite to be installed and connected to the foundation. One critical aspect of complete buildings in OSC is logistics management as the building itself is to be transported to the site location, which involves not only site access but also route access inspection. All the considered literature on types of OSC included complete buildings within modules which does not differentiate the two. Therefore, **Complete buildings** are another typology of OSC which involves a significant amount of offsite skills and an extremely minimal amount of onsite skills due to the overall completion of the building within a factory facility.

4.6 FLAT PACK

Interestingly, none of the authors who took part in defining types of OSC (Table 1) included flat pack manufacturing to consideration even though it has been in the industry for more than a decade. Many authors have identified flat-pack to be available in the OSC industry; as a complete building manufacturing and assembly method (Goodier and Gibb, 2004), as an example of bathroom and kitchen manufacturing in UK (Pan, *et al*., 2008), as a mode of floor manufacturing using timber (Lawson, *et al*., 2014), and a popular OSC mode in Australia (Boyd, *et al*., 2013).

Current industry practice reveals more advanced uses of flat pack OSC, where even the onsite assembly is less prevalent. A Swedish construction firm (Skanska) in collaboration with famous IKEA furniture manufacturers, apply flat pack technique for OSC, leading to minimal onsite work by using standard parts and reducing project construction time to half (The Economist, 2017). Furthermore, a USA based OSC firm (MADI) manufacture the complete building indoors within the factory, fix the floor, wall and roof panels to each other using hinges, fold all components to be a single pack and simply unfold the building after cautious transportation to site (MADI, 2019). This allows easier transportation for the entire building which is not visible in other complex typologies of OSC. **Flat pack** is the final typology of OSC where onsite skills requirement becomes insignificant.

5. CONCLUSIONS

The research aimed to develop typologies of OSC, that resemble the current advanced technology involvement in the construction industry which also reduces the traditional onsite skills usage. Typologies are of six number; **components, panels, pods, modules, complete building and flat pack**. These were developed after rigorous scrutiny of literature on both available types of OSC and latest industry practices. Therefore, the developed typologies of OSC is the most updated and reliable version of OSC which indicates different combinations of onsite and offsite mixes. Furthermore, MMC categories introduced by (MMC Working Group, 2019) also incorporates similar typologies with different terminologies which justifies the development process.

Findings of this study suggest that, OSC has evolved through the years from the initial four types to more progressions. The paper has highlighted the usage of complex technology by the industry practitioners in order to meet the absolute targets of offsite constructed structures. Therefore, the current findings add to a growing body of literature on typologies of OSC which is a significant component of industrialisation. It contributes

to the field of OSC by introducing a logical approach to identify typologies of OSC. However, these findings are limited by the use of secondary data from literature sources. Therefore, it is recommended that further research to be undertaken by collecting data from primary sources which will also be a validation of the current study.

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