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OFFSITE CONSTRUCTION SKILLS PREDICTION: A CONCEPTUAL MODEL

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ABSTRACT

Industry 4.0 driven technological advancements have accelerated the uptake of Offsite Construction (OSC), causing the need for re-skilling, up-skilling, and multi-skilling traditional onsite construction skills and competencies. The purpose of this paper is to develop a conceptual model that predicts OSC skills as a response to the OSC demand. The paper is a theoretical presentation of a skill profile prediction model which introduces the key concepts, OSC typology, OSC skill classification and their relationships. Components, panels, pods, modules, and complete buildings represent the OSC typology. Managers, professionals, technicians, and trade workers, clerical and administration workers, machine operators and drivers, and labourers constitute the OSC skill classification. The conceptual model takes the OSC project parameters: gross floor area, OSC value percentage and skill quantities as input and provides predicted skill variations as the output. The skills are quantified in "manhours/m2" under six skill categories, for five distinct OSC types. As such, the research presents a comprehensive conceptual model for the development of an OSC skills predictor to capture the skill variations and demand in a construction market moving towards rapid industrialisation. The research contributes to the existing body of knowledge by identifying the key concepts, parameters, and mutual relationships of those parameters that are needed to develop a realistic prediction of future trends of OSC skills.

Keywords: *Conceptual Model; Offsite Construction; Prediction; Skills.*

1. INTRODUCTION

Offsite construction (OSC) has attracted growing research interest in the recent past (Goulding and Pour Rahimian, 2020; Smith and Quale, 2017). OSC is the manufacturing of buildings or functional elements of buildings in a factory to be transported and assembled onsite (Blismas, et al., 2009; Goh and Loosemore, 2016). OSC has always been a part of traditional construction as some building elements such as doors, windows and light fittings are not constructed onsite by any means (Arif and Egbu, 2010; Gibb, 2001). However, Industry 4.0 and its technological advancements have influenced OSC to the extent that the entire building may be manufactured in a factory to be simply

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transported and fixed onsite (Ginigaddara, et al., 2019; MADI, 2021). On the other hand, OSC offers a pathway to rapid industrialisation of the sector improving its production capabilities and efficiency (Goulding and Pour Rahimian, 2020).

OSC is a fusion of manufacturing and construction know-how, eliminating long-known efficiency shortcomings of the construction sector (Goulding and Pour Rahimian, 2020; Pan, et al., 2012). Traditionally, built construction is inherently less productive due to its heavy reliance on skilled labour (Karimi, et al., 2018). Moreover, it is prone to health and safety risks, less sustainable, and creates uncertainties in time and cost management (Goh and Loosemore, 2016; Smith and Quale, 2017). These factors have led to the popularity of OSC with key research aspects such as productivity improvement (Eastman and Sacks, 2008; Wuni, et al., 2021), production process optimisation (Zhang, et al., 2020), economic value addition (Taylor, 2010), and multi-skills development (Arashpour, et al., 2018; Nasirian, et al., 2019). Industrialisation-driven technological advancements improve OSC processes (Ginigaddara, et al., 2022; Goulding and Pour Rahimian, 2020) and its impact on OSC skills are yet to be found. OSC skills are different from traditional construction skills, and hence there is a critical need to identify and develop such OSC skills (Brennan and Vokes, 2017). However, the limited research on OSC-specific skills has created a knowledge gap in OSC research.

It is believed that the identification of OSC skills facilitates skills prediction, providing a platform for skill creators; industry practitioners, education providers, professional institutes, and the government to understand, be aware of, and support the development of necessary OSC skills to match the job market's demand. The paper presents the rationale for OSC skills prediction, key concepts and parameters behind OSC skills prediction, the proposed conceptual model, its innovation, and the current research conducted on OSC skills.

2. RATIONALE FOR OSC SKILLS PREDICTION

The term "skills" in this research refers to job roles or occupations under both professional and vocational work categories. Researchers suggest that OSC results in the emergence of new skills while some skills become redundant, and some skills can be easily substituted from the manufacturing sector (Gann, 1996; Goh and Loosemore, 2016; Smith and Quale, 2017). Industry 4.0 based technological advancements become a driver for such variations in OSC skills due to the involvement of robots, co-bots, exoskeletons, and similar human-machine integration (Adepoju, et al., 2022). These technologies are introduced to the market with a fascinating level of modernisation, to improve productivity and efficiency in skills utilisation (Farmer, 2016). As the construction industry is renowned for its poor labour productivity (Eastman and Sacks, 2008), the term "skills" in OSC can also be misinterpreted as a measurement for labour productivity. Labour productivity is a factor used to measure the relationship between labour inputs and production outputs (Eastman and Sacks, 2008; Parchami, et al., 2019). Previously, Tatum, et al. (1987) introduced a productivity measure for OSC labour usage considering the labour costs at each stage of production, transportation and onsite assembly. However, this research focuses on a rather broader concept to understand how the skills utilisation may vary for different types of OSC.

Depending on the features, level of OSC adoption and the degree of industrialisation involved in different OSC types, the skill requirements may vary. Such skill variations or patterns can be visible in two ways: usage of different kinds of skills, and the usage of different quantities of skills. Once the OSC skills are manifested, the next step can be productivity evaluation of OSC skills and multi-skilling, and they are beyond the scope of the current research. As such, this research proposes a conceptual model for OSC skills prediction, where the skills variations in unique OSC types are evaluated based on the quantity of different skills involved in each OSC type.

3. KEY CONCEPTS AND PARAMETERS

3.1 OSC TYPOLOGY AND OSC TYPES

OSC types have unique features and distinctive outcomes (Smith and Quale, 2017). Gibb (2001) classified different OSC types into component manufacture and sub-assembly (door, furniture), non-volumetric pre-assembly (panels, pipework), volumetric pre-assembly (toilet pods, plant rooms), and modular buildings. This classification was then exploited by various researchers but was modified to accommodate industry practices and different terminologies. This paper uses the OSC typology consisting of non-volumetric (components, panels) and volumetric (pods, modules, complete buildings) categories (Ginigaddara, et al., 2019). Components (light fittings, trusses) are non-volumetric elements of any shape or size excluding flat panels, while panels (floor, wall, ceiling panels) are flat elements that do not create usable space (Gibb, 2001; Pasquire and Gibb, 2002). Pods (bathrooms, prisons) are repetitive items with a high level of finishing (Goh and Loosemore, 2016), and modules (apartments, school buildings) are a part of a whole building (Bertram, et al., 2019). Several modules create a single unit or a complete building (site sheds, disaster recovery buildings) (Ginigaddara, et al., 2019).

3.2 OSC SKILL CLASSIFICATION AND SKILL CATEGORIES

Vokes, et al. (2013) categorised OSC skills under primary (design and project delivery), secondary (contribute to project delivery - assembly of components) and tertiary (supportive functions – office administration) roles. Later, six functions were introduced to classify OSC skills: digital design, estimating/ commercial, logistics, offsite manufacture, onsite assembly and placement, and site management and integration (Brennan and Vokes, 2017). Recently, the Construction Industry Institute (2021) classified OSC skills under three categories: design and engineering, construction and fabrication, and administrative.

Detailed skill classifications are available in country-based labour statistics databases (Australian Bureau of Statistics, 2019; Office for National Statistics UK, 2020; US Bureau of Labor Statistics, 2021). Yet none of them specify OSC skill classifications which can be due to the difficulties in differentiating OSC among construction and manufacturing sectors. These literature findings highlighted the need to develop a skill profile classification to recognise the OSC skills that are different from traditional construction skills. Based on the Australian Bureau of Statistics (2019) data, Ginigaddara, et al. (2021) classified OSC skills under managers, professionals, technicians, and trade workers, clerical and administration workers, machine operators and drivers, and labourers. This classification of six skill categories comprising of 67 potential OSC skills is incorporated into the conceptual model for OSC skill profile prediction. Apart from the key concepts discussed, three additional parameters; skill quantity variations, gross internal floor area of the building, and OSC value percentage of the OSC type are used to quantify skills used in OSC projects. They were selected to derive at a predictive measure for OSC skills.

3.3 SKILL QUANTITY VARIATIONS

OSC is a promising solution for the expanding onsite skills shortage (Blismas, et al., 2009) and high labour costs (Jaillon and Poon, 2008) as Industry 4.0 driven technological advancements facilitate up-skilling, re-skilling, and multi-skilling of traditional construction workforce (Goh and Loosemore, 2016; Hairstans and Smith, 2018). It is anticipated that skills usage varies depending on the OSC type, and their unique manufacturing techniques (Bertram, et al., 2019). Skill resource requirements refer to the total number of manhours required to complete an OSC project. They are recognised as onsite (construction site) and offsite (factory, office, and transportation) skills under the six skill categories.

3.4 GROSS INTERNAL FLOOR AREA (GIFA)

GIFA is an alternative measure for building cost that exempts the area of non-volumetric and vertical building elements such as wall panels and components (Jaillon and Poon, 2008). Besides, previous studies have also used GIFA as a suitable building parameter opposed to project duration and cost (Love, et al., 2005; Monahan and Powell, 2011). Therefore, GIFA (measured in m2) is considered to derive a “per unit measurement” for skill quantification. It is anticipated that GIFA provides a comparable measurement for skill profile prediction that can be repeated for any number of scenarios. For example, once the skill quantities of an OSC project are quantified in manhours, the GFA measured in square meter facilitates a measure (manhours/m2) that can be applicable to a similar OSC project.

3.5 OSC VALUE PERCENTAGE

Lawson, et al. (2014) specify the OSC value in components, panels, modules, and complete buildings of a construction project to be 10-15%, 15-25%, 30-50% and 60-70% respectively. However, Prefab Logic (2019) reports that the OSC percentage of many building projects adds up to 90-95% within the factory. Similarly, several other companies achieve high OSC percentages by adopting innovative methods (MADI, 2021; Ten Fold Technology, 2018). A case study review of OSC project costs in Western Australia reveals the offsite cost portion to be between 71-73 percent (Sutrisna, et al., 2019). As such, it is expected that diverse OSC types possess varying OSC percentages in a given OSC project, and hence it is considered one of the key attributes in the conceptual model. The value percentage of a particular OSC type can be calculated by dividing the total cost incurred for design, manufacture, and assembly of that OSC type by the total cost of building construction.

4. CONCEPTUAL MODEL FOR OSC SKILLS PREDICTION

A conceptual model combines key concepts and inter-concept relationships as a graphical illustration (Leedy and Ormrod, 2019). The conceptual model (Figure) incorporates skill quantity variations under different skill categories.

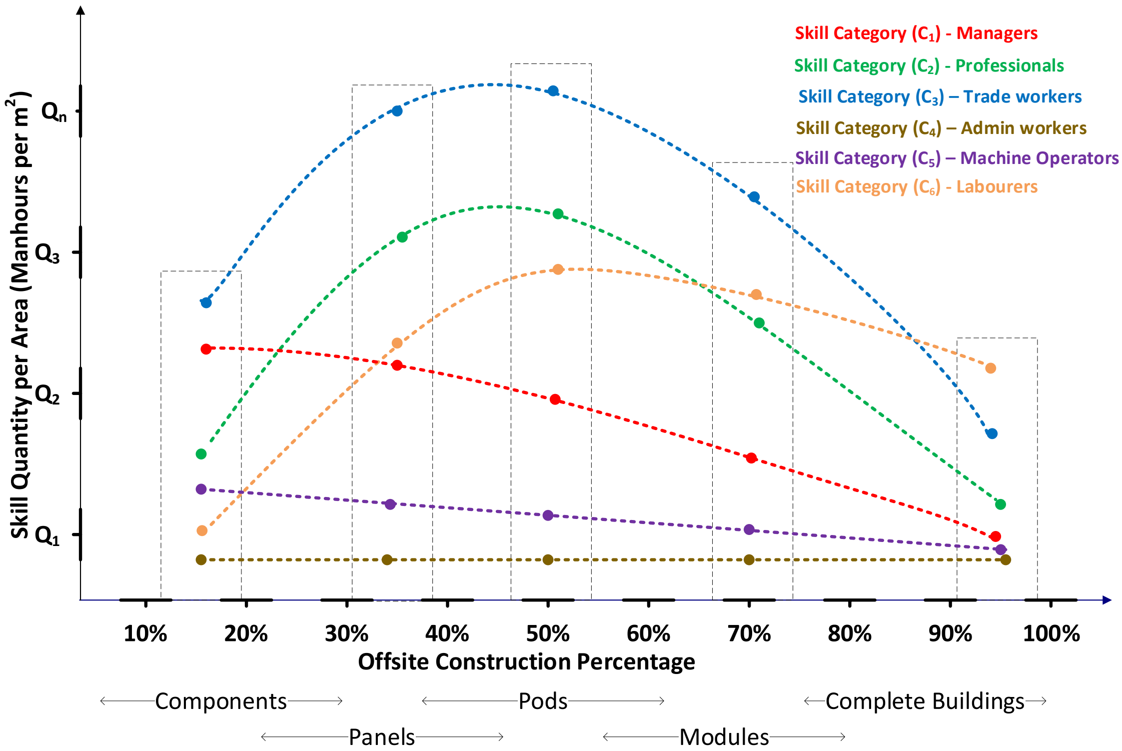

Figure 1: Conceptual model for offsite construction skills prediction

The variable, skill quantity per area (measured in manhours/m^2) recognises the different skill quantities of six skill categories under five distinct OSC types. Quantities of each skill category are expected to vary depending on the relevant OSC type, and their relationships are yet to be found using empirical data. A series of case studies of OSC projects will provide the basis to calibrate the skill profile prediction model. As such, skills quantities utilised in OSC projects, along with their GIFA and OSC value percentage need to be collected and analysed via regression analysis to adjust the curve representing each skill category. Once this process is completed, it will be apparent whether the relationships are linear (straight lines) or non-linear (curved lines). It is possible that some skill categories will be directly proportionate to the complexity of the OSC type, and thus linear relationships can appear.

Moreover, there can be complex skill variations depending on the level of automation involved in OSC types. For example, the number of trade workers and machine operators needed for a particular OSC type may vary depending on the prefabrication method adopted. The use of robotic arms with assembly line-based manufacturing processes may result in some skills being in high demand whilst the demand for other skills is substantially reduced. As such, the lines in Figure 1 resemble the possible skill variations for the six skill categories under five distinct OSC types.

The empirical data-based skill prediction model (OSC skills predictor) will forecast the potential skill quantity required to complete an OSC project. The expected OSC type, its value percentage and the GIFA of the building are the data inputs. Skills predictions will be generated for the six skill categories under onsite and offsite locations. For example, a modular OSC project of 1000 GIFA, with 70% OSC value percentage may require the following skill quantities: managers - 500 manhours, professionals - 1000 manhours, trade workers - 1500 manhours, admin workers - 125 manhours, machine operators - 250 manhours, and labourers - 1100 manhours. The onsite and offsite usage of each skill category may also vary. Furthermore, longevity of the OSC skills predictor will be assured by inserting the actual OSC project data, so that it can evolve with the market conditions of various skills usage. Once developed, the OSC skills predictor can be used as a mobile or a computer application.

5. INNOVATIONS OF THE CONCEPTUAL MODEL

Among the well-documented aspects of OSC research, several publications focus on OSC-specific skills development (Vokes, et al., 2013; Brennan and Vokes, 2017; Hairstans and Smith, 2018; Ginigaddara, et al., 2022). Despite the numerous models developed on skills optimisation (Arashpour, et al., 2018; Nasirian, et al., 2019), research on skills prediction for a mix of both traditional and OSC approaches are limited. The proposed conceptual model captures OSC-specific skills under six skill categories from managerial positions to labourers. Moreover, skills prediction accounts for the various types of OSC prevalent in the industry. Identification of both these aspects; OSC types and the skill categories was achieved by following systematic research processes which involved a rigorous literature review. Furthermore, the skills prediction model provides a unique skill quantifier, "manhours/m^2" which can be used to predict the magnitude of skill shortage and supply for any OSC type, under any skill category, for both onsite (construction site) and offsite (factory, office, and transportation) aspects separately. Recognising the different skills usage assists in pre-planning, and accurate budgeting of OSC project labour costs. Moreover, the skills prediction model proposes a forecasting tool to be used by regulators and tertiary education providers, industry training and professional bodies to decide on the labour market demand and requirements. Also, OSC skills prediction will be useful for new entrants to OSC businesses, to get an overview of the OSC skills under a specific OSC type, for a given OSC value percentage and GIFA.

6. FURTHER RESEARCH IN MODELLING OSC SKILL REQUIREMENTS

The conceptual model introduces an original framework to predict OSC skills in a quantitative stance. In related research, a state-of-the-art typology for OSC has been developed (Ginigaddara, et al., 2019). Other work also has evaluated skill profile classifications relevant to both traditional and OSC skills, evidenced in Australia (Ginigaddara, et al., 2021). Other research has applied digital procurement technologies such as Blockchain to supply chain management that can be adopted in OSC (Perera, et al., 2020). Current work is also exploring development of process protocols for integration of DfMA and blockchain for the OSC sector. Another outcome of the ongoing research work is to propose a validated prototype for OSC skills prediction highlighting the research findings and the methodology of developing the OSC skills predictor.

7. CONCLUSION

OSC is the production of construction elements in a factory fundamentally moving construction of buildings from an onsite process to offsite. The advent of Industry 4.0 has exacerbated the offsite construction methodologies breaking the established typologies for OSC to novel approaches. Although construction is far behind other industries in terms of industrialisation and digitalisation, OSC facilitates the industrialisation of the construction industry to improve the delivery of factory-made buildings and building elements/components. Evidently, the adoption of new technologies changes the traditional construction skills to embrace advanced technologies. Therefore, the future of construction skills in an OSC setting is not known, and thus creates a knowledge gap to be filled through research. This paper introduces a conceptual model that incorporates key concepts of OSC typologies and building areas to predict construction skills requirements. The identified concepts are the OSC typology and the OSC skill classification representing all possible skills. Further, GIFA of the completed OSC projects, value percentage of the OSC type, and the skill quantity variations are considered to develop the conceptual model. As such, OSC skills prediction incorporates the unit of measurement, "manhours/m^2" to quantify skills under six skill categories for five distinct OSC types.

The conceptual model for OSC skills prediction is the first of its kind. Also, the work presented contributes to the body of knowledge by introducing a methodology for OSC skills prediction. The research identified and integrated the key concepts, parameters, and their interactions in a prediction model to anticipate the emergence and expansion of OSC skills. Once developed, the OSC skills predictor will be presented in the form of a mobile or a computer application. It can be used by regulators, policymakers, education providers, and industry practitioners to understand the demand for various OSC skills based on the market conditions for distinct OSC types. It is anticipated that the actual data collection and analysis will lead to recognising the skills based on their location of work - onsite and offsite as well. The paper has inherent limitations of being a theoretical study, as it aims to present a conceptual model for OSC skills prediction. However, other research publications associated with this conceptual model will present empirical studies to develop an OSC skills prediction model using case study-based skills data.

8. DATA AVAILABILITY STATEMENT

No data were generated or analysed during the study.

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