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Modular coordination-based generative algorithm to optimize construction waste

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Abstract

In response to the growing attention to sustainable built environment, this study aims at introducing an approach in construction waste optimization through integrating parametric design with offsite construction methodology. To this end, a generative algorithm was developed within the integrated platform of Rhino and Grasshopper software based on modular coordination rules and ASTM international standards as the design constraints in modules array. Two sets of horizontal and vertical modules were obtained from a prototype model while an evolutionary solver function was employed for optimizing the generated waste. This resulted in developing different modular design variants which generate the minimum amount of waste while being fully compliant with international standards. This study contributes to the field by presenting one of the first studies in its kind focusing on the integration of parametric design into offsite construction methodology through the lenses of construction waste optimization.

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Keywords: Offsite construction; parametric design; generative algorithm; modular coordination; waste optimization.

1. Introduction

Offsite construction is an attempt geared towards increasing productivity, time efficient delivery and mass production on construction projects via using manufactured houses, panelized components and prefabricated

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structural frames. This refers to a construction system in which components are manufactured in a factory, transported and assembled into structures with minimal on-site activities [1]. Modular Coordination (MC) is a key asset in deploying of offsite construction. That is, MC is a pre-engineered structure that entails creation of discrete-volumetric pre-fabricated components in light of coordination of dimension and space. MC is a methodology which drives offsite construction towards adopting an integrated design according to a basic unit or module and encourages parties involved in the construction industry to produce and utilize prefabrication to facilitate mass production of buildings in a standardized format [2]. Delivering projects through implementing MC results in great benefits such as lowering environmental impacts, enhancing productivity and facilitating effective project handling [3]. Despite such advantages, current implementation rates are far from satisfactory. For instance, the utilization rate among residential building projects in the US is below 3% [4]. That is because, use of MC makes project delivery prone to a wide range of complications in terms of the design scope and exploration options. The special challenge is the need for transforming conventional design and construction practices to an approach based on MC in which the creative design options are to be explored and generated. To overcome this challenge, parametric design can be effectively applied to deliver the generative modeling of pre-designed sets of rules and explore various design schemes [5].

Parametric design allows for generating innovative compositions in a formal and conceptual manner by the virtue of implementing a group of criteria in line with MC rules. Nevertheless, a review of literature shows that there is a lack of research that looks into coupling MC with parametric design to enhance the processes applied in offsite construction. This gap is especially widened where the sustainability performances and environmental impacts of offsite construction come to the light. Construction waste constitutes 40% of landfilled materials [3], yet full settlement of such a damage seems a long way off. There is no shortage of research studies that focus on waste minimization aspects of modular construction by either conducting surveys [6] or case studies of real-life projects [7]. Likewise, application of innovative design methods in modular construction through integration with BIM processes [8] and BIM authoring tools [9] have recently come to the fore as active research areas. However, no research study has hitherto investigated construction waste optimization through the lenses of integrating MC and parametric design. To address the identified gap, this study aims at developing a novel approach geared towards construction waste optimization in which MC principles of offsite construction are simulated through parametric design and different design options are explored using a generative design algorithm. Adhering to the minimum amount of generated waste, the study concludes with presenting a number of schematic deliverables. These could be translated into guidelines for architects and practitioners to facilitate preventing waste during the design.

1.1. Modular coordination (MC)

MC aims at standardizing the measurement and placement of building components according to a number of dimensional coordination rules within a referenced system [9]. MC facilitates dimensional compatibility among the size of a building, its associated spans or spaces, the size of components and any equipment used. A three dimensional integer lattice provides the reference arrangement and a module identifies the typical unit for the components. These dimensional coordination principles are used in prefabrication and offsite construction to identify the optimum dimensions for components, reduce on-site waste and simplify their interchanges [10]. Five major rules of MC are provided below [9].

- Using modules as the basic, multi and/or sub modules
- Defining a reference system to coordinate spaces and zones
- Locating building elements within the reference system
- Measuring building components to specify work sizes
- Identifying the building layout and coordinating the dimensions for buildings

A basic module forms the fundamental entity of size and dimension in MC while the sizes of building components and the building layout are coordinated in multiples of this basic module. This equals to 100 mm (M) and could be defined in n*M which results in multi-modules. The basic module is addressed through a reference system which is composed of a system of points, lines and planes to establish a basis of layout for building