



Integration of parametric design into modular coordination: A construction waste reduction workflow



Saeed Banihashemi^a, Amir Tabadkani^b, M. Reza Hosseini^{c,*}

^a Faculty of Arts and Design, University of Canberra, Canberra, Australia

^b Department of building and architectural engineering, Politecnico di Milano, Milano, Italy

^c School of Architecture and Built Environment, Deakin University, Geelong, Australia

ARTICLE INFO

Keywords:

Waste reduction
Design stage
Parametric design
Modular coordination (MC)
Generative algorithm
BIM
Workflow

ABSTRACT

The construction industry is under pressure as to reduce the sizable quantities of construction waste generated during construction operations. Modular coordination (MC) and parametric design both have great potentials in reducing waste at the design stage. And anecdotal evidence suggests that great volumes of waste can be reduced through integration of parametric design into MC. The issue of proposing workflows in this context, however, is under-researched, and practical applications, if any, are at the rhetorical stage. To accomplish this, an integration attempt is made in this study to provide the details of a developed-and-experimented workflow for this purpose; a generative algorithm is developed through the Rhinoceros 3D–Grasshopper platform, subject to MC rules. Two sets of horizontal and vertical modules are obtained from a prototype model, while an evolutionary solver function is applied in reducing the generated construction waste volume. According to a pre-defined standard specification, different modular design variants that fully conform to the design constraints in modules array are developed, providing an operational workflow in construction waste reduction at the design stage. Introducing this workflow, and how the proposed workflow reduces the volume of post-optimization paneling waste by 2% at its minimum are the major findings here. The insights derived from this study, would promote the interest of both the construction practitioners and researchers; the practicality of integrating parametric design into MC is proven.

1. Introduction

Construction waste is defined as materials or products that need “to be transported elsewhere from the construction site or be used in-situ for other applications than the intended specific purpose of the project due to damage, excess or non-use, or which cannot be used due to non-compliance with the specifications, or which is a by-product of the construction process.”

[1] Construction operations have many detrimental impacts on the environment, like depletion of natural resources and generation of sheer quantities of construction waste, among others [2,3]. There exists a pressure for reducing the construction waste volume [4,5]. In waste management policies, to implement construction waste reduction in an effective manner, the issue should be dealt with at design stages [6,7].

The emergence of Building Information Modeling (BIM), rich in digital information, can facilitate the actualization of this major issue. BIM improves communication among project stakeholders, provides better planning, and reduces raw material consumption, through providing accurate measurements [1]. With all these said and done, many of the BIM potentials with respect to waste reduction at design stages

remain to be assessed and implemented [7]. In practical terms, lack of accurate and standardized dimensions of components in early design phase is a major barrier [7].

Designers in practice need to deliver generative modeling(s) of pre-designed sets of rules, to explore various design schemes, and apply their domain-specific knowledge into BIM authoring tools [8,9]. Anecdotal evidence has promoted implementing Modular Coordination (MC) as one of the solutions in meeting these requirements [10,11].

The parametric design principles provide a common platform for both MC and BIM, where, generating innovative compositions, applying a group of criteria in line with MC rules in authoring tools, and automating intricate modeling activities be accomplished [12,13].

A review run on the related literature, reveals that the available studies on this context are almost entirely conceptual, or are based on practitioners' perceptions [13,14]. The most relevant study on this topic is conducted by Singh et al. [9], where the potentials for integration of MC and parametric modeling capabilities of BIM are explained. However, to date, there exist no integrated MC and parametric design proposed through a practical workflow within the reflected literature.

* Corresponding author.

E-mail addresses: Saeed.Banihashemi@canberra.edu.au (S. Banihashemi), seyedamir.tabadkani@mail.polimi.it (A. Tabadkani), reza.hosseini@deakin.edu.au (M.R. Hosseini).

To address this identified drawback, at the objective here is to introduce a practical automated workflow where MC principles are simulated through parametric design, and the design quality is enhanced through a generative design algorithm. This study will be of interest to both researchers and practitioners due to its: (1) establishing the practicality and potentials of applying a workflow in integrating parametric design into modular coordination, and (2) presenting a practical case of implementing the workflow, as a workable procedure for reducing construction material waste at the design stage.

2. Background

The construction industry is notorious to be one of the largest contributors to waste generation, and a heavy consumer of raw materials [3,10,15]. At global scale, construction activities generate about 25% of all the solid waste, even in most advanced economies [5]. The volume of generated construction waste is on a constant increase [16]. About 40% of the material dumped in landfills are of construction waste [10]. Consequently, the construction industry has become a top priority as to making attempts to reduce the volume of consumed material and waste generated thereof [1,3,7].

Waste is generated during different stages of construction lifecycle, particularly during the construction phase [15,17]. A major part of waste is generated, however, due to the wrong decisions made and inappropriate actions at the design stage [1,2,16]. Consequently, enhancing design-oriented methods to support waste reduction has become a priority [1,14], regarded by many assessors as the key strategy in construction waste reduction [6,11,18]. It is claimed that construction waste reduction through design can reduce around 33% of the total volume waste generated in delivering construction projects [1,16]. With respect to the design stages, applying modular construction through implementing modular design strategies is regarded as one of the most effective approaches towards avoidable waste reduction [6,19,20].

2.1. Modular construction and BIM

As discussed, designing a building according to modular construction principles substantially reduces the volume of waste when executing construction activities [21,22]. Modular construction entails applying three-dimensional sections or modules which are manufactured in a precast plant prior to shipment to construction sites [10]. Thereby, the method offers a great potential for reducing material consumption, reducing reworks and poor on-site workmanship quality, eliminating various waste streams [20,22,23]. Tam et al. [24] assessed the construction waste reduction impacts of building projects by applying different modular elements, and deduced that this wastage can be reduced by 35 to 100%. Likewise, Jaillon and Poon [25] revealed a construction waste reduction rate as high as 65%, while Jaillon et al. [26] estimated an average level of 52%, attributed to implementing modular construction.

Despite the advantages, modular construction implementation introduces new requirements at design stages. Designers need to develop accurate, well-structured building models that would enrich production planning and support the manufacturing needs [21,27]. These models are essential enabling on modular construction that should represent different elements, provide information about details of products, and find correlation among all the components included in building models [28]. The potentials of BIM at design stages in facilitating and implementing the modular construction is contributive in accomplishing these requirements [28–31]. This is justified when the BIM authoring tools are based on parametric design principles [32–34], and that modular construction can significantly benefit from the great level of design flexibility provided by parametric design capabilities of BIM [30,31].

Emergence of object-based parametric design as the underlying

logic of BIM tools is changing the nature of design practices in the construction industry (Eastman et al., 2011). As defined by Monedero [35], parametric design implies the use of parameters in defining a form when what is actually involved is the use of correlations. In parametric design, computational attributes and different levels of artificial intelligence are applied in setting the design principles in providing a platform for design assessment [36–39]. These include rules, constraints, parametric dependencies, heuristic and the meta-heuristic structures to encode them [32]. The procedure of parametric-generative design constitutes the following four major elements [33,40]:

- The beginning conditions and parameters (input)
- A generative mechanism (rules, algorithms, etc.)
- The variants generation (output)
- The best variant selection

Each generative process begins with some inputs to establish the initial parameters, which, next, are transformed into a generative mechanism towards the initial population of design [36]. This mechanism can entail instructions, rules and/or algorithms to fulfill a specific purpose in certain steps [37]. Upon generation of variants and various design schema, a benchmarking or a selection procedure is determined to identify the best variant and the final output [40]. There exist no best solution; rather an iterative divergence/convergence process which would provide the most comprehensive range of possibilities and then explore, analyze and identify the best design option with regards to the desirable criteria as defined by Eltaweel and Su [33] would serve the purpose.

The parametric design capabilities of BIM, makes designers flexible: define a wide range of variants, divide building models into objects and components of different size, control the relations thereof, and explore various alternatives against pre-defined criteria [28,41]. These capabilities make BIM an ideal tool for implementing MC, an effective modular construction strategy for reducing construction waste [9,13].

2.2. Integrating parametric design into modular coordination (MC)

Waste minimizing capabilities of modular construction increase where larger parts of buildings are made up of prefabricated components, in form of modules [19]. This is because, installing modules results in elimination of waste in terms of variability options and the error margins of products [42,43]. A module is defined as “a basic dimension which could, for example, form the basis of a planning grid in terms of multiples and submultiples of the standard module.” [44] This dimension equals to 100 mm (M) and can be defined in $n \times M$ that results in multi-modules. Modules' use at large-scale in buildings necessitates the implementation of MC, a dimensional coordination system that defines sizing, and places building modules within a 3D reference system according to several dimensional coordination rules [9,23]. The five major rules of MC [13] are:

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

In MC, a three dimensional integer lattice provides the reference arrangement, where, a module identifies the typical unit for the components [9]. The dimensional coordination of these modules together with other objects at design stages are of paramount importance [30,45]. These dimensional coordination principles, can introduce the generative mechanism of parametric design to identify the optimum dimensions for components, and simplify their interchanges [42,43].

Consequently, harnessing the full benefits of modular construction

Download English Version:

<https://daneshyari.com/en/article/6695800>

Download Persian Version:

<https://daneshyari.com/article/6695800>

[Daneshyari.com](https://daneshyari.com)