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Modular coordination and BIM: Development of rule based smart building components

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Abstract

The introduction of computing tools to Architecture, Engineering & Construction (AEC) industry has enabled the professionals to navigate successfully from traditional design/ drafting to Computer Aided Design/Drafting (CADD). Furthermore, the industry is slowly transitioning towards sophisticated Building Information Modelling (BIM), which necessitates the integration of domain specific knowledge into the BIM authoring tools. The approach presented in this paper elucidates the development of rule-based BIM objects which allows a designer to create building models within the rules of Modular Coordination (MC). With this development, a designer will be able to use MC standards to size and locate building objects in a modular reference frame. Integration of rules of MC with BIM authoring tool will enhance the design process and allow designers to automate some complex modelling/documentation activities requiring no design expertise. The development of rule-based BIM objects exploits the parametric modelling capabilities of BIM authoring tools in addition to visual programming tool to automate the modelling process. The research first explains development of rule based BIM objects which is extended to streamline the overall design process. The presented approach discusses the customization of BIM authoring tool for modelling a residential facility in MC using axial planning of structural elements. In the prototype system, the designer is guided by specific rules and constraints while providing sufficient options to develop variegated configuration. The integration of design rules of MC standards with BIM application will be influential to increase radical use of BIM for built environment especially in the prefabrication industry.

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Keywords: modular coordination; BIM application; customization; rule based BIM objects; parametric modelling.

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1. Introduction

The "manual expression" of designer's expertise is required for a handcraft like design of built environment [1]. Researchers have described the design process for built environment as an information intensive, iterative [2], evolutionary and complex process [3], [4]. Utilizing the traditional project delivery approach, AEC industry professionals use raster documents to share information among themselves. The inefficiencies of traditional 2D paper based approach are now well documented as well as understood. A minor change in design invokes either updating all models and drawings or there will be inconsistencies and lack of coordination [5]. Moreover, 2D drawings are the only way of information exchange among the professionals [6] and the coordination among them primarily depends on the expertise of designer. So, when designers engage themselves in high value adding tasks such as decision making, analysis of alternatives, experimentation with shapes; they are also responsible for low value production related tasks such as data processing, information retrieval, design-documentation and coordination.

The induction of BIM authoring tools has enabled the industry to mobilize its resources from production oriented tasks to decision making tasks [7]. Because of its model-centric and object-driven core, BIM by its very nature reduces the low-value production related activities performed by the designer. So, BIM is positively changing the balance between high-value decision making efforts and low-value production oriented efforts. The customization of BIM authoring tools can make the design process more efficient and reduce the efforts expended by designers on repetitive and redundant tasks.

With the objective of streamlining the design process, this research was conducted to understand the process and methodology of customizing and enriching BIM authoring tools with domain specific information and knowledge to assist the designer in enhancing value-creation in the design process." By utilizing the concept of rule-based modelling to BIM authoring tools for MC, this research work demonstrates the "computer as an agent" [8] construct. Exploiting the parametric modelling feature and visual programming tool associated with BIM authoring tools, this study explores possibility of developing rule based building objects for associating MC rules. The aim of integrating MC rules will be primarily to assist designers during the modelling process which has been extended further for streamlining overall design process.

2. BIM Authoring Tools for Modular Coordination

The BIM practice allows design professionals to shift the efforts to early stage, making the value adding decisions more effective [9]. On the other side, MC enables co-operation among design professionals and other stakeholders via dimensional coordination. In conjunction with BIM, modularization and off-site fabrication are the enabling concepts and practices have significant impact on US construction industry [10]. Moreover, BIM and MC enhance the design and construction process by improving the communication among the project participants [11]. The need of pre-project planning and coordination issues among design professionals has created the need of implementing BIM on complex projects [12]. The BIM practice facilitates the organization of activities like planning, design-analysis, development of drawings, fabrication schedule, construction schedule etc. Also the proliferation of model-driven fabrication of building objects, BIM authoring tools have increased reliability on prefabrication techniques [13]. In a way, BIM practice has the potential towards increased use of pre-fabricated modules and also modular coordination [14].

3. Review of Literature

BIM can be defined as a process of developing building model for analysis, documentation and several more related activities in virtual environment at various stages of building life cycle [15]. In other terms, it is a process of creating an intelligent and computable nD data set [14], in which BIM authoring tool works as an enabling platform for updating and sharing information in efficient manner [15]. In the BIM process, the information is stored digitally at single place which can be accessed and modified for generating various construction documents, eliminating the need of creating information for different purposes, hence, reducing inconsistency issues. However, the efficient use of

these modelling tools can be only realized when the information has been created at appropriate level of details [16]. The modelling tools have potential to reduce efforts required for production oriented tasks such as visualization, quantity take-off and information exchange. CADD tools enable professionals to create 3D model which is more or less geometrical representation of building objects [17] whereas BIM authoring tools allow object-oriented modelling in which elements are represented as virtual building objects [18] [19]. Thus, in a way, BIM authoring tools offer an enabling platform for integrating domain specific information. Sometimes, BIM authoring tools are also considered evolved version of CADD tools for modelling buildings [20] and described as CADD + specifications [21].

Modular coordination is a standardization system based on dimensional coordination system for sizing the building components and placing them within a reference system [22]. It has a three-dimensional integer lattice acting as a reference and module as the smallest unit [23]. Prefabrication and industrialized production system uses this dimensional coordination to optimize the number of sizes for particular component [24], reduce on-site waste and ease interchangeability of components.

Parametric Modelling Capability of BIM Authoring Tools – The geometrical relationship among objects such as alignment, separation etc. [25] and visual, thermal or mechanical properties of building objects are defined using variable known as parameters. Parametric modelling feature allows regeneration of geometry based on geometrical constraints [26]. Moreover, using explicit mathematical expressions, parametric modelling features allow to integrate domain specific knowledge [27]. The predefined set of rules for modelling building facility using parameters in BIM authoring tools reduce modelling and technical flaws [28]. nD design capabilities and distributed intelligence of BIM authoring tools offer an integrated and automated design environment, which can reduce errors through automated design verification [29].

4. Research Methodology

As illustrated in Figure 1; the research involves study of various MC standards and examination of modelling process in BIM authoring tool. This is followed by development of rule based BIM objects where various rules to be incorporated are listed, alongside, various options available in BIM authoring tool for customization. For developing rule based building objects, several building components such as doors, windows, wall panels etc. are modelled with parametrical constraints so that these components are customizable under MC standards. MC rules such as alignment, 5 mm rule and tolerance are incorporated as geometrical constraints while others rules are incorporated as suggestive messages. Modular reference frame can be created using the parametric and generative capability of BIM authoring tools. The objects developed in the previous step are also intended to streamline the overall design process such as design documentation, visualization, quantity take-off and information sharing.

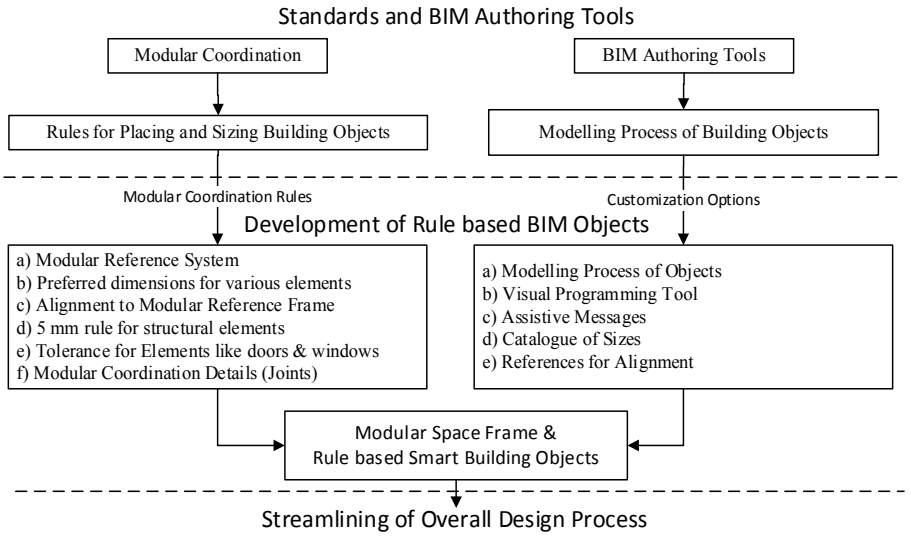

Figure 1: Research Methodology

5. Development of Rule based BIM Objects

The design or modelling in MC starts with the creation of a three-dimensional integer lattice termed as modular reference frame. The frame consists of reference planes spaced at a distance of module or multi-module as per standards. The prefabricated building components can be placed in the project referencing to these planes. As explained in figure 2, rules for placing building components can be incorporated by creating modular reference frame and creating aligning planes or lines associated with objects. The reference planes associated with the BIM objects will interact with modular reference frame and guide the modeler to place it in the project. Rules for sizing the building components can be incorporated during its modelling process, using various options such as assistive messages, visual programming tools to adjust parameters and size catalog.

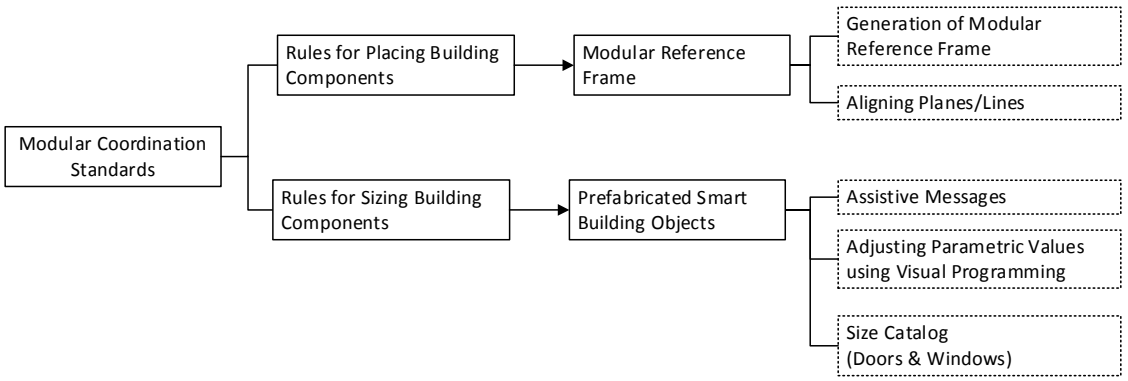

Figure 2: MC Rules and Options for Developing Rule based BIM Objects

5.1. Modular Reference Frame

As it can be inferred, from MC standards and design practices, the reference frame is starting point of design process in MC. For creating reference frame, the designer requires planes represented by lines along x-, y-, z-directions. The study utilizes visual programming tool for this task as it is sequential and based on logic that can be converted in explicit mathematical relationships.

5.1.1. Generation of Modular Reference Frame

Visual programs have been developed to generate the grids of reference lines and levels. As explained in figure 3, the first part generates the list of values which can be used as multi-module, followed by inputs from designer to select appropriate values for the project. After designer's input, the program perform simple mathematical operations and generates lines which can be converted into column grids. Similar to this, another visual program has been developed to generate levels which will provide references in z- direction.

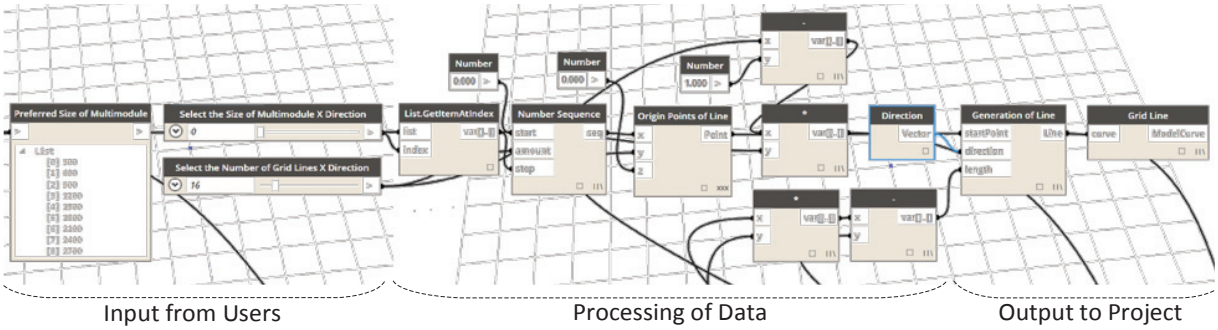

Figure 3: Visual Programming Flowchart to Generate Grid Layout

5.1.2. Aligning Planes/Lines

In this study, axial placement of structural elements has been taken into consideration to place them. As shown in figure 4, reference planes are associated with the BIM objects during the modelling process. These reference planes can be used to align them to the modular reference frame. Several MC details such as joints, 5mm rule for structural elements and tolerance for various elements are captured during modelling process with the help of reference planes and lines.

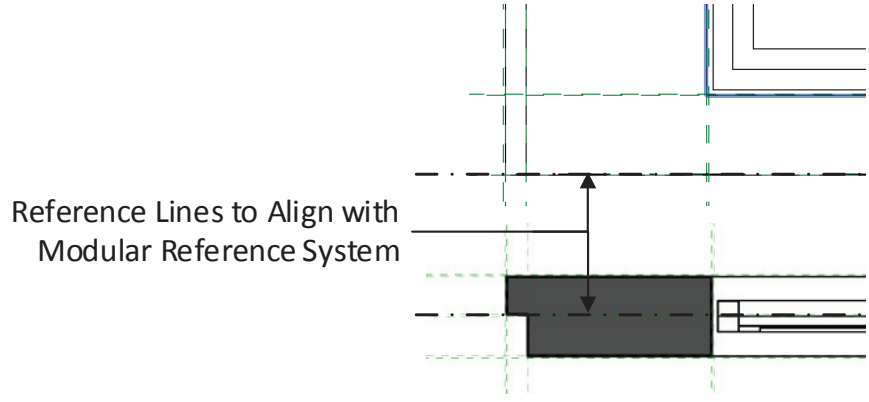

Figure 4: References Lines/Planes to align Rule based BIM Objects to a Modular Reference Frame

5.2. Rule based BIM Objects

Before a designer can embed the domain specific knowledge or rules, there is a need of modelling building objects with geometrical constraints, parameters and construction details. In this study, several prefabricated building objects such as wall panels, slab panels, doors, windows, stairs etc. are modelled. As explained in figure 5, various rules for sizing the components according to MC rules have been identified, alongside options to incorporate the rules as discussed in subsequent sections.

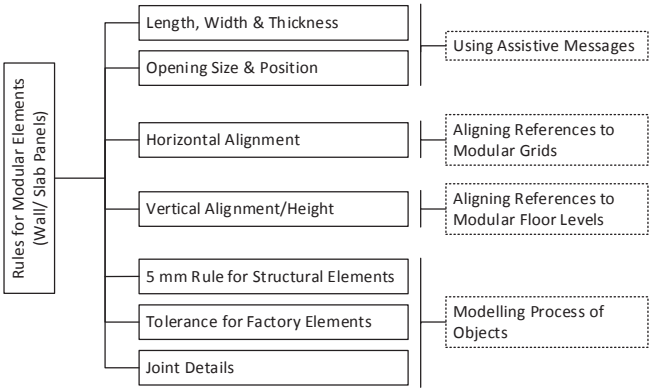

Figure 5: Rules and Options for Modelling Rule based BIM Objects

5.2.1. Assistive Messages

This option can be used to display assistive information to the designer, when there is a deviation from modular sizes for particular building component. As explained in figure 6, assistive messages are created during the modelling process of object and visibility parameter has been associated with the messages. The value of visibility parameter depends on a conditional statement which allows it to appear in the project environment when there is a deviation from standard size.

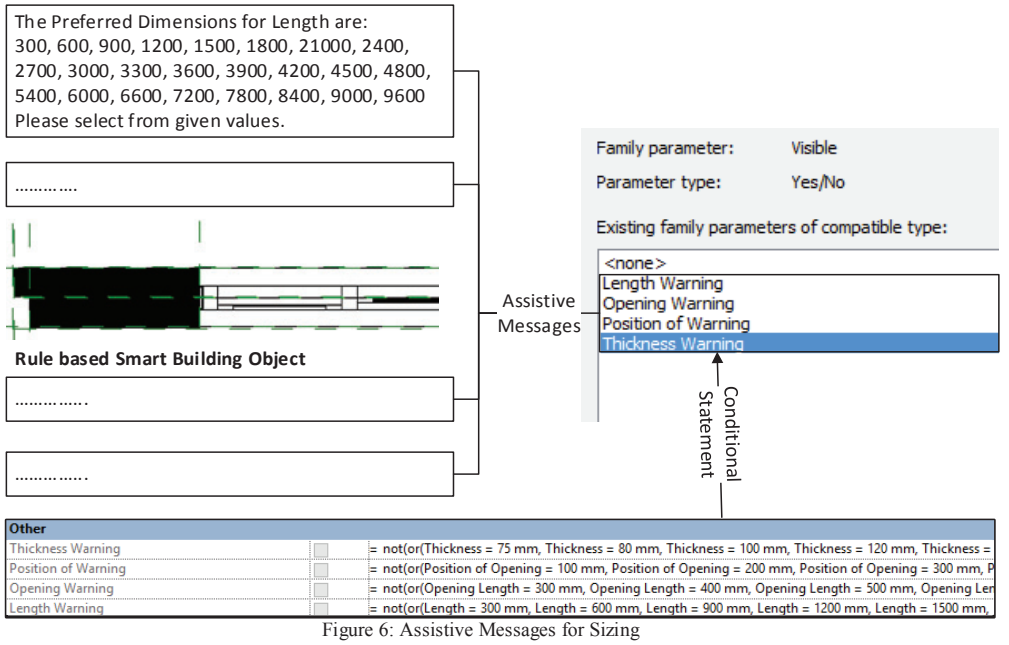

Figure 6: Assistive Messages for Sizing

5.2.2. Adjusting Parametric Values using Visual Programming Tool

The visual programing tool can be used to modify value of parameter for particular building object. As discussed in figure 7, a visual program can be developed first to generate values, followed by associating the value with suitable parameter. A list of values can be used to guide the designer about dimensions possible for the parameters.

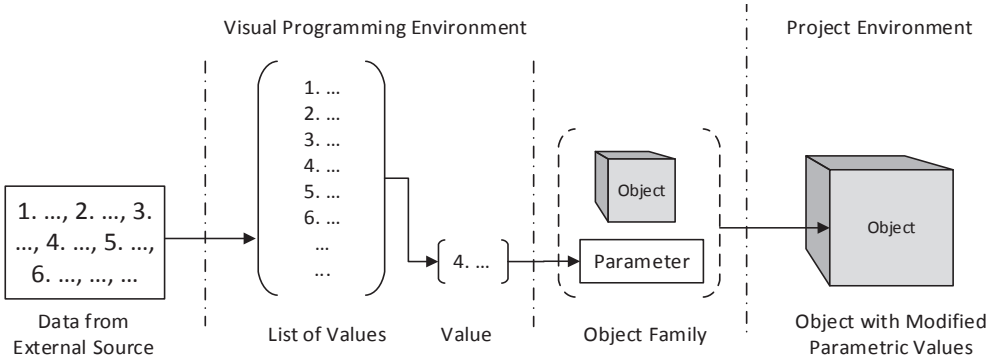

Figure 7: Visual Program for Modifying Values of Parameters

5.2.3. Size Catalog (Doors/ Windows)

This option is suitable when there are several combinations of values for parameters are possible for particular building component under MC rules such as door and windows. Spreadsheet applications can be used to generate suitable set of values for parameters. The *"type catalog"* option can be used to create combination of length and height for doors & windows possible under MC rules. As explained in figure 8, the object is developed which has geometrical components controlled by parameters, then the values of these parameters can be controlled using separate input file.

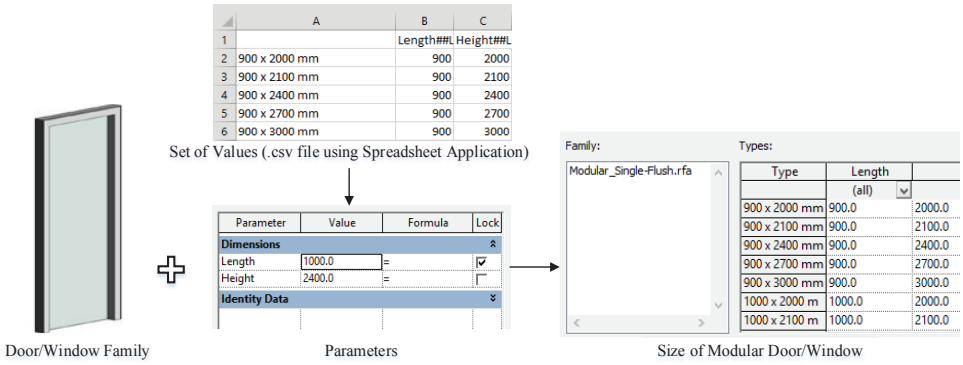

Figure 8: Adding set of Values for Parameters to Door/ Window Family

6. Streamlining Overall Design Process

The objective of the research work is not only to improve the modelling process in BIM authoring environment but to enhance the overall design process also. After creating smart modelling elements, the designers will be able to reduce their efforts on production oriented tasks such as documentation, visualization, quantity take-off etc. As explained in figure 9, while developing rule based BIM objects, information sharing parameters and identity parameters are associated with the elements for documentation and sharing information. After integrating appropriate information, the developed building model will have all the required information for documentation such as 2D details, visualization properties and quantity take-off process. The associated parameters can be used to generate the information in tabulated format.

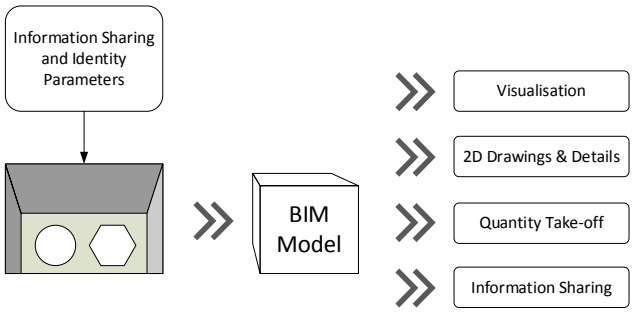

Figure 9: Adding set of Values for Parameters to Door/ Window Family

7. Conclusions

The domain specific knowledge can be incorporated in BIM authoring tools by modelling rule based BIM objects, parametrical constraints and visual programming tool. The integration of domain specific knowledge in modelling tools is helpful and reduces the efforts expended by the designer in production oriented tasks. Modelling using rule based BIM objects not only reduces efforts in modelling process but streamlines the overall design process using automated design verification, generation of coordinated drawings and various schedules for construction activities. The built-in intelligence of BIM authoring tools reduces the design inconsistencies. The generic intelligence of BIM authoring tools can be extended further for specific projects such as for integrating knowledge for region specific standards, information for data extraction and guidelines for acoustical space. However, every domain specific information cannot be integrated using the method explained in this study and application programming interface can be used for such purposes.

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