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Building skins, parametric design tools and BIM platforms

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Abstract

The parametric design tools could be considered one of the digital creativity tools for the architect. BIM platforms trend to simplify the work of designers and engineers if they keep their products within the standards. Then, creativity and information modelling are frequently in contrast within the digital construction field. An interaction between parametric design and BIM platform is necessary to avoid the influence of predefined parametric elements on the design concept. This paper will discuss the recent use of parametric design tools as Grasshopper and DynamoBIM within BIM process. Furthermore, how the geometrical solutions could be arranged to optimize the interactivity of the final models.

Keywords: BIM, Parametric Design, Responsive Skins, 3D modelling, Generative Design.

1. Introduction

The contrast between the concept of free form design, which the parametric design offers, and the standardizing concept, which characterize BIM platforms, is huge. However, the combination of the two methods is the best ingredient for a flexible information model, which does not ignore creativity. Moreover, it extends the model for programming functions. The generation of parametric skin elements for example and including them within an information model permits to get real time feedback from the BIM platform about the model according to specific input parameters. Therefore the use of parametric design connected to BIM is convenient in early stages of design to make decisions according to the results data and the form.

2. Methods of parametric design

Parametric Design is the production of a parametric model basing on specific variables. The input variables could be dimensions, quantities or geometries. **That means, given a parametric design, different inputs produce different designs.**

Parametric modelling concept, which is the core of parametric design, is existing in almost every 3D modelling software and particularly in BIM platforms by way of object-based parametric modelling (walls, Columns...). Parametric model has Parameters, constraints and relationships. The concepts of parametric modelling extends from a simple parametric box with parameters (length, width and height) and constraints (parallel segments) to a complex entire architecture with thousands of variable including parameters and geometries. Since modelling tools are various and the possibilities are several, then the discussion about the methods to use parametrization in BIM model is worthwhile. Defining a workflow involve different tools and affect the flexibility of the parametric model then the way to alter the final design. Principally, the parametric Design methods for designers within BIM are three:

- Using Object-based parametric modelling
- The parametric approach within conceptual design environment
- The visual programming

2.1 Object-based parametric modelling within BIM platforms

The use of predefined architectural and construction elements within the project environment is the simplest parametric design method, normally it is not considered as a parametric design method since it uses a limited approach of parametrization. Architectural elements in BIM platforms have standard constraints and predefined relationships. Creating the parametric objects such as walls columns and mullions and then forming parametric relationships between them produces a parametric design. Since this method uses a direct approach to create objects, define relationships and constraints between objects without any control of the workflow. Then, most likely, in big models, the user will lose control of the design workflow and the model will be easily overloaded by contrasted constraints.

Therefore, the parameters of standard build-in objects added to the constraints and the parametric relationships between objects leads to big parametric models with simple geometries and it does not need additional tools to parametrize the model. However, since it is based on the control of the parameters but not the workflows, it is hardly useful for models with complex geometries and for models with expected variations in its creation workflow.

2.2 The parametric approach within conceptual design environment

This method is graphical geometry-based one, which create parametric models defining variables and the constraints directly within the geometry. This method is the closest one to the classical CAD concept for 2D and 3D objects but it support the addition of constraints, variables and formulas to connect variables. This way the user can combine the advantages of the free form design with the parametrization.

The main concept of this approach is to create free-form surfaces or volumes. The volumes could be solids or voids and they could be an input for an interactive Boolean operation such as intersection or subtraction of other volumes, surfaces or Architectural elements such as walls. Therefore the integration between a free form shapes and standard architectural elements produce complex geometries without making use of algorithmic design tools

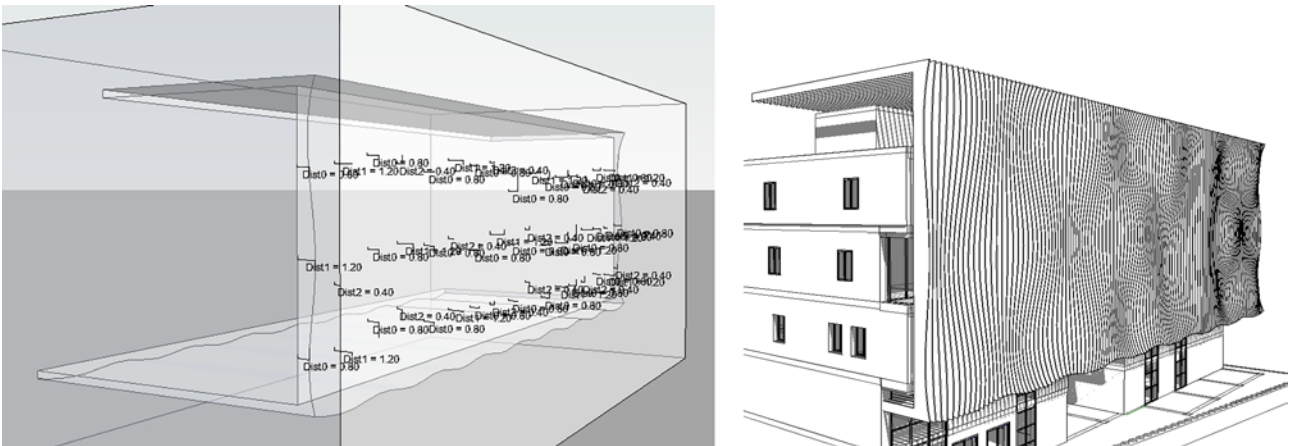


Figure 1: Parametric architectural skin created by subtracting a parametric mass volume (left) from vertical wall elements to produce a series of vertical cross sections of waved skin (right). The parametric mass is a parallelepiped, which contain a parametric void with different variables. Changing the variables produces automatically new waves of the skin cross sections in the project. Model by the author, project by E. Pataracchia, V. Pucello & F. Rossin (Autodesk Revit).

A particular method of conceptual design is the adaptive geometry where a series of relationships of the model finish up to be dependent on the position of some particular points called Adaptive Points. The Adaptive point position is variable and then when the final model is inserted in a specific project the adaptive

points will take their position and basing on their coordinates the model will automatically be edited and adapted to this specific case. Adaptive models are very useful in pattern-based skins. This method permits to create complex geometries, to add mathematical formulas for the parameters and it free the user from the predefined constraints but it does not include workflow control and the parameters are practically limited to dimensions.

2.3 The visual programming

Designing frequently involves establishing visual, systemic, or geometric relationships between the parts of a design. More times than not, these relationships are developed by workflows from concept to result by way of rules. Typically, designers work algorithmically defining a systematic set of actions that follow a basic logic of input, processing, and output. Programming allows us to continue to work this way but by formalizing our algorithms. Since an algorithm is a set of steps to accomplish a task, visual programming for design is called Algorithmic Design too. Moreover, it is called generative design since it generate the design from giving inputs according to the designer algorithm. It is a completely new approach where the designer defines the relationships and the variables for an imagined design but not a specific final model.

This method is free from any constraints and open to scripting. It is based on algorithmic modelling tools, which are typically add-ons to 3D modelling software. Visual programming permits to define all the three inputs of a model Variables, constraints and relationships.

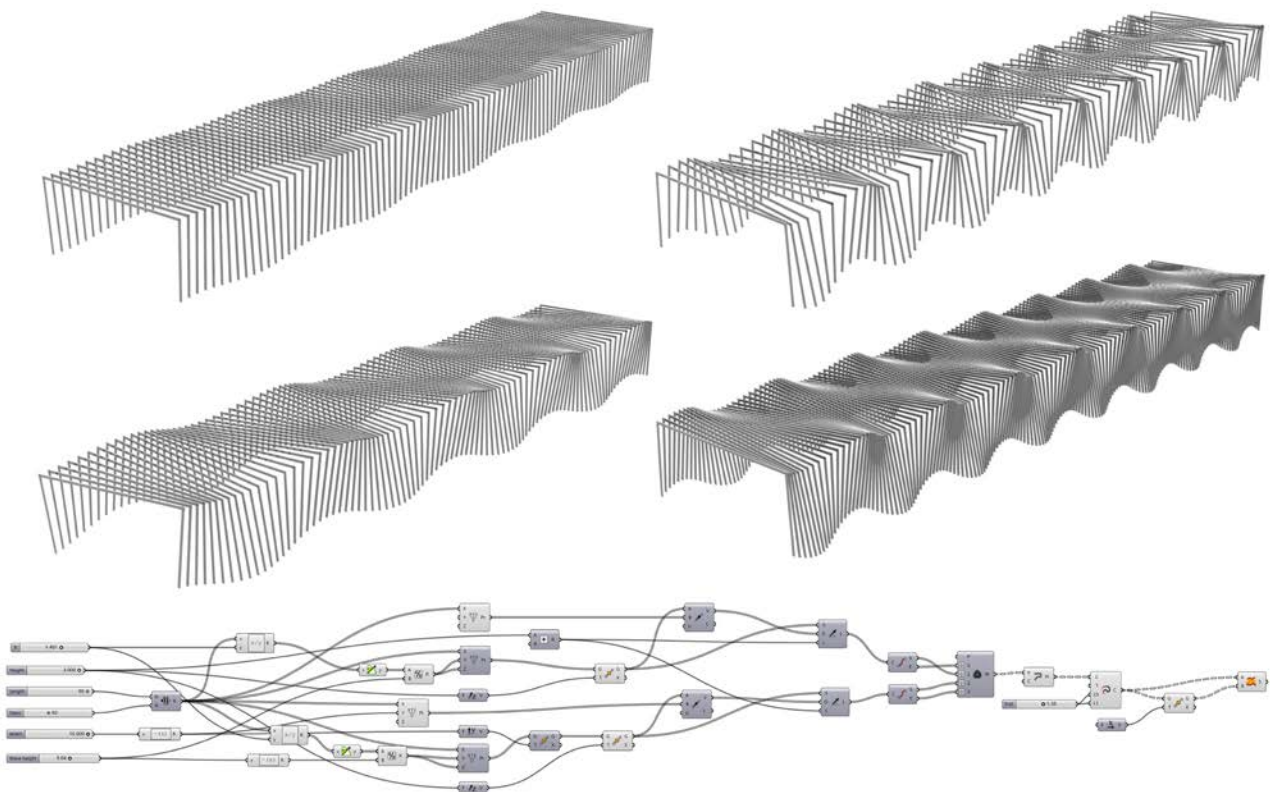


Figure 2: Parametric definition inspired by the station of Reggio Emilia in Italy a project of S.Calatrava. The frames of the model are defined by a formula with variables. Changing variables produces different model outputs. Model by the author (Grasshopper and ArchiCAD).

This method provides the possibility to add any type of variable as quantities dimensions to create conditions, switches, formulas and to keep the workflow history. Therefore it permits much more than any other method such as the very complex geometry with a full control of the modelling workflow from the very

beginning until the end. Additionally, designers can add switches between different solutions and a full control of the output calculating quantities and dimensions within the code directly. Moreover, it is possible to create conditional variables as attractors or random effects.

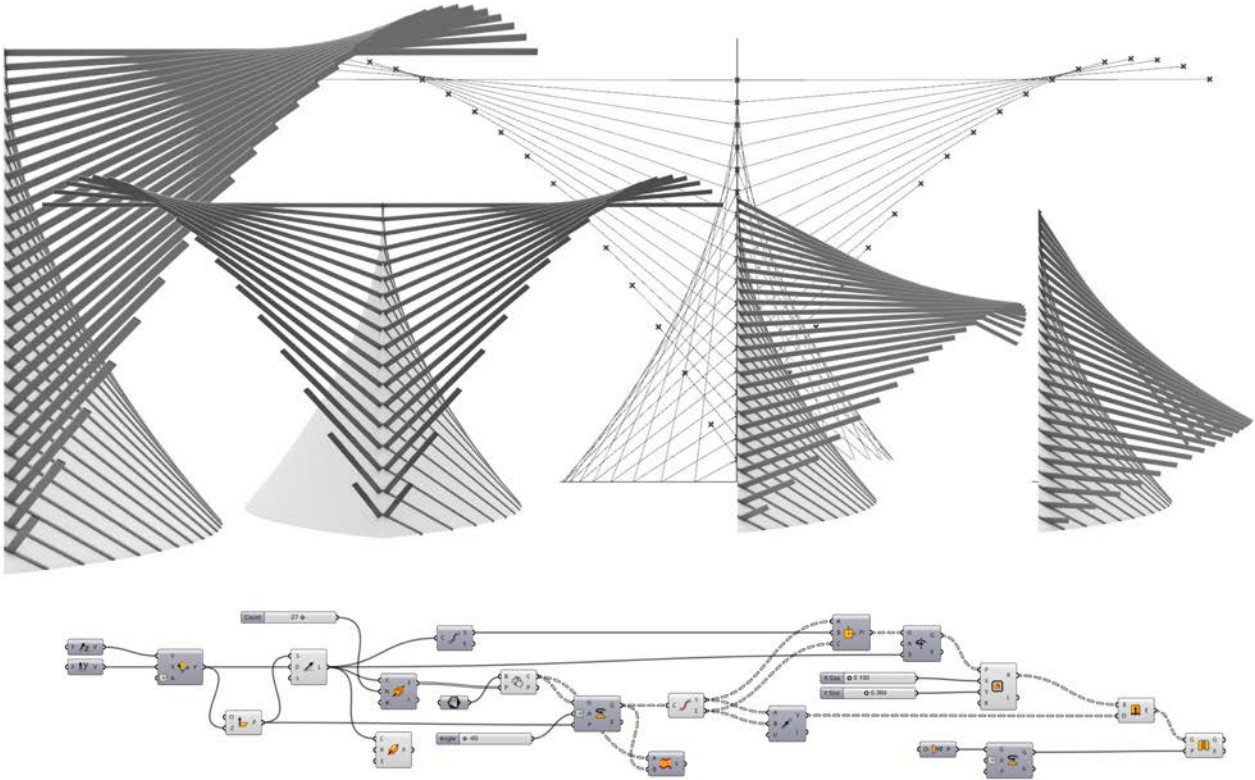


Figure 3: Parametric definition inspired by Milwaukee Art museum by S. Calatrava. Parametrizing the movement of the bars within ArchiCAD permits to study the shadows and the energy analysis basing on the aperture. Model by the author (Grasshopper and ArchiCAD).

3. Algorithmic modelling tools and BIM platforms

Actually nowadays, the producers and the users of BIM software packages are trying to connect their product to some algorithmic design tools directly or even indirectly to exploits the benefits of such a tool and to extend the use of BIM to the early stages of design. The engagement of those tools in an early phase of the design is useful to keep under control all the calculations of the models and to open the model to the possibility to integrate some script codes when it is need. The codes, which are part of the algorithmic modelling system, could be related to the geometry of the architecture or to process automatic solutions. In many cases within the building skins field, the design of the skin could be defined even in later stages of the project. Therefore the direct integrate of the skin algorithmic model in the BIM project is very important. Main advantages of the use of algorithmic design tools are:

- Keeping control of the whole or partial process
- The possibility to copy and apply an algorithmic complex process to different objects.
- Having a real-time feedback using documenting processes.
- Scripting (from visual scripting to text-based scripting)

The most diffused up to date algorithmic modelling tools, which could be connected to BIM platforms, are:

- Grasshopper3D (plugin for Rhino and could be connected to ArchiCAD)

- DynamoBIM (plugin for Revit or Vasari & Stand-alone)
- Marionette (natively available within Vectorworks software)
- Generative Components (plugin for Bentley)

Grasshopper is a visual programming editor developed by David Rutten at Robert McNeel & Associates. As a plug-in for Rhino3D, it is without doubt the leading tool for algorithmic design. It started from the idea to have explicit control over this history of the modelling workflow. When McNeel & Associates introduced Grasshopper in 2007 for its Rhino3D modelling tool, everything became visual. While scripting in Python or higher languages is still a useful tool for the dedicated computational design fan, Grasshopper introduced a very simple, plug, play and wiring interface, which built the script in the background. Programs are created by dragging components onto a canvas. As a result, Grasshopper and Rhino is a popular combination at the likes of Zaha Hadid, Buro Happold, HOK Sport and Foster + Partners.

Dynamo is a community-driven open source graphical programming for design released by Autodesk in 2011 to support its software such as Revit Vasari and Maya with algorithmic design. The direct connection of Dynamo algorithmic design to Revit means for Revit users an extension of BIM experience and exceed many limits. Then in 2015, the company developed the sandbox version, which works independently as stand-alone version and intended to be a bridge between non-Revit users and Revit based projects.

Archicad is a popular BIM tool, which is part of the Nemetschek group, has been lagging its competitors in computational design, despite Archicad's powerful built-in GDL parametric development language. Therefore, Graphisoft choose to exploit the popularity of Grasshopper and to connect Archicad to it. Then, those architects who have learnt to use Rhino and Grasshopper can now also run their scripts in Archicad and drive a full Building Information Modelling (BIM) model. After six months public beta phase involving over a thousand architects and designers worldwide in April 2016 Graphisoft has released its Grasshopper-Archicad Live Connection at that point Graphisoft has gone from nowhere in generative design to being able to run the most popular, free, computational design package on the planet.

Grasshopper and Dynamo are very widespread, their online communities are relatively big, and developer users are contributing with a huge amount of add-ons, which can extend them. Large libraries of user-created packages are available online.

Other prevalent parametric tools to be used in BIM environments are Vectorworks, one of the first software to introduce BIM capabilities, is now part of the Nemetschek group too. It offers a build-in algorithmic design tool, Marionette; it is open to developers too; Then, Generative Components a parametric CAD extension by Bentley, which developed to integrate with Building Information Modelling as extension Feature to Bentley's AECOSim Building Designer.

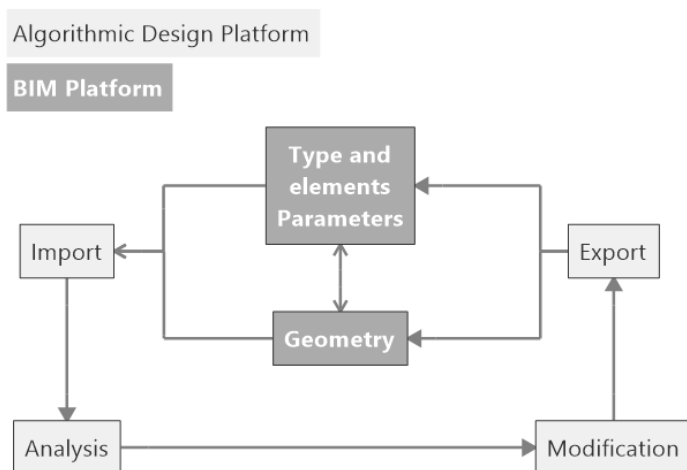


Figure 4: Workflow to import data from BIM platform to algorithmic design platform then back to the BIM

The interaction between the BIM model and the algorithm is fundamental in the Design phase. This

interaction is possible through two-way data exchange. Data include geometry or parameters. Algorithmic design tool reads data from BIM platform. As well, it exports parameters and geometries to the BIM platform (Figure 4).

This includes reading and rewriting parameters within architectural elements and families in the project model and the creation of new objects in the project. Another function is documenting, which reports the values for documentation or analysis without affecting the geometric properties of an element.

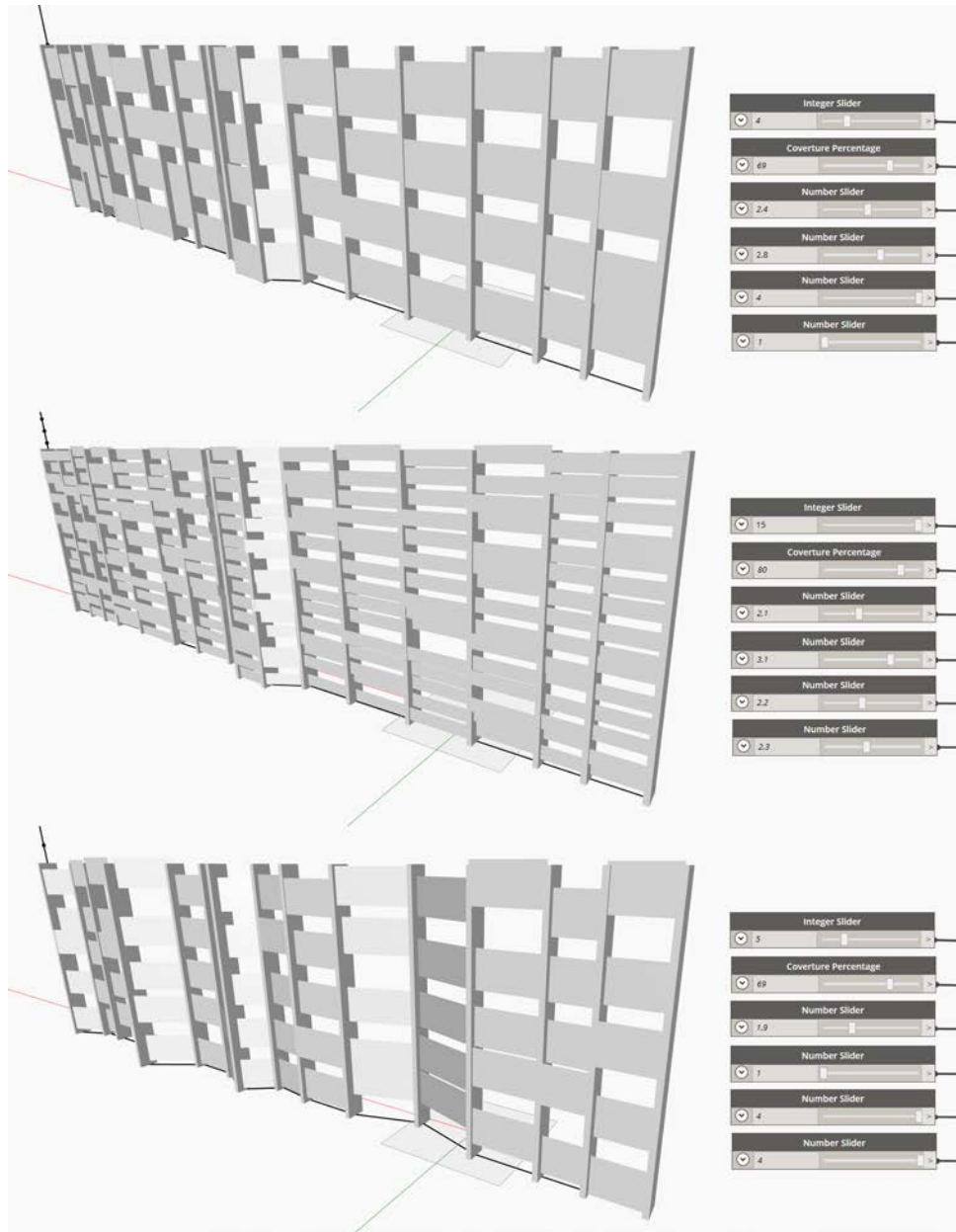


Figure 5: Experimental Façade as interdisciplinary parametric model. It includes parameters to be defined by Energy specialist, Architect and structure engineer. The Structure engineer can define the quantity and the section size of the columns using Revit families. Then, using the code, energy specialist can define the aperture percentage of the façade and the Architect can define the quantity and the distribution of the panels within the Façade surface. The figure shows different compositions according to different inputs. The code created with Dynamo and the model is in Revit by the author.

To transfer data of an element from BIM model to the algorithm we can recall parameters from two levels, type parameters and instance parameters. Editing type parameters will affect all the elements of the same type within the model but editing instance parameters affect only one element. This function leads to an interaction between model and script. The parametric design therefore can be defined by a collaboration between many specialists using the same flexible parametric model.

An experimental model done in our school is the model of a façade, which is defined by a code from an architect. The code starts selecting automatically series of columns of type (Façade_ Column) defined by the structure engineer. Structure engineer can define the size of the section of the column type according to its structural calculations. The code imports the columns and create automatically panels between them according to variables. The first variable requested from buildings energy specialist, who provide the percentage of the aperture in the total surface of the façade according the energy analysis. Then the architect has the possibility to change the quantity and the distribution of the panels according to the desired design (Figure 5). This is an example of an interaction between local elements in BIM platform and parametric design by algorithmic tool.

Algorithmic design workflow might use this Hybrid workflow interacting with BIM platform or it could be clearly separated from BIM project. In many cases, algorithmic modelling is dedicated and limited to the preliminary design only, and the model is to be exported and detailed in the BIM platform. This depends on many factors such as:

- The maturity of the idea
- The quantity of needed variables
- The complexity of the model (geometry)
- The relationship with other objects in the project (constraints and limits)

4. Conclusions

Parametric design using algorithmic tools is convenient in many cases for Building skins. Using parametric design of the skin within BIM platform has many advantages such as the use of BIM benefits. Moreover, to keep the skin in the same BIM model of the main structure of the building. However, the extension of BIM to Algorithmic design need some considerations. The workflow of the model construction has to be defined at the beginning especially in big models with more than one specialist to make decision in the Design phase. At this point, the designer has to define which variables are to be defined within the model elements parameters and which are to be defined within the algorithmic code. BIM shifted big quantity of the work to the beginning of the modelling process compared to CAD and with parametric design; on one hand, we are shifting more work to the beginning to define codes creating parametric models. On the other hand, those parametric models could produce unlimited solution permitting to shift the final design decision to the end of the process.

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