Closing the loop

From analysis to transformation within BIM

Stefan Krakhofer[1]

[1] City University of Hong Kong
stefankrakhofer@gmail.com

Abstract. The shift from traditional CAD to BIM has created a significant potential to embed optimization processes in many stages of the design. The presented research is situated in the early design stage of inception and concept, focusing on analysis-driven-form-finding during the integrated design approach within a BIM environment. A custom analysis framework, has been developed and linked to a visual programming environment that allows the exchange of data with the parametric components of a BIM environment. The developed workflow and sequential split of functionalities enables a shared design environment for multiple experts and the design-team.The environment is intended to close the loop from analysis to parametric modeling in order to generate and evaluate building designs against performance criteria, with the aim to expedite the design decision process. The prototype has been presented to participants of the Deep-Space Cluster at SmartGeometry 2014.

Keywords: Algorithmic Design, Parametric Design, Parametric Analysis, Building Information Modeling, Design Automation.

1 Introduction

Since the adoption of computers in the architecture, engineering and construction (AEC) industry, the mode of practice has experienced a paradigm shift, transforming from post-rationalization, and pre-rationalization to embedded rationality.

1.1 Post-Rational Approach

In the post-rational workflow, the building is design by the architect according to his or her best knowledge. Afterwards the building's performance is analyzed and evaluated, and improvements with minimum visual impact to the original design are recommended.

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1.2 Pre-Rational Approach

In the pre-rational workflow, the building is design by the architect with a rational in mind that may address the structural system, the material selection, the overall architectural geometry [1], etc. During the design process the design is developed within the adopted constraints, potentially resulting in an optimal solution.

1.3 Embedded-Rational Approach

The embedded rational workflow relies heavily on computation due to the necessity ofcombining performance assessment and form finding in a single iterative system [2]. Aishargues that the embedded rational approach is '*the most appropriate to truly open ended design optimization'*[3].Despite the potential benefits, the pure embedded rational workflow seems at this point only rarely operational, when taking into account the general design practice.

1.4 Integrated Design Approach

As an alternative to the pure computational embedded rationalization approach, the integrated design approach presents a collaborative method that emphasizes on holistic design. The focus of this method is on well-organized and well-managed design data and a collaborative environment.In the past ten plus years this approach has gained momentumwith the transition from traditional Computer Aided Design (CAD) to virtual building design titled as Building Information Modeling (BIM).The shift from traditional CAD to BIM has created a significant potential to embed optimization processes in many stages of the design.

The presented research is situated in the early design stage of inception and concept, focusing on analysis-driven-form-finding during the integrated design approach within the BIM environment, Autodesk Revit. From a sustainable point of view, the early design stage contains the most potential to achieve an increase in building quality, performance and cost savings in the long run. Targeting these benefits, the integrated design approach emphasizes on early information sharing in order to achieve the desired outcome fast, efficiently and effectively [4]. The integrated design approach is affecting the design process as shown in figure 1, by shifting the main body of work from the centertowards the beginning of the process.

Due to the importance of effective and efficient information sharing, the core of the presented research is on defining the transition points between various project partners and specialist in respect of form finding for performance enhancement. In respond, the first prototype in form of a custom analysis framework has been developed and linked to a visual programming environment that allows the exchange of data with the parametric components of a BIM environment. The developed workflow and sequential split of functionalities enables a shared design environment for potentially multiple experts and design-teams.The developed environment is intended to close the loop from analysis to transforming parametric models in order to generate and evaluate building designs against performance criteria, with the aim to expedite the design decision process.

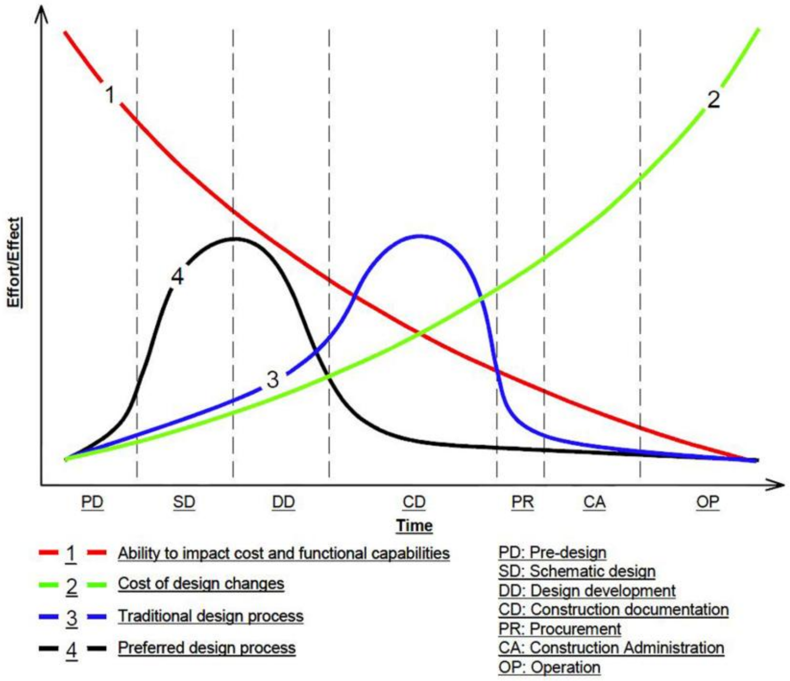

Fig. 1. Design approach and effect comparison. [4]

1.5 Design Equalizer – Task Separation

During the analysis of workflow and best practice, it has been noted that architecture design projects rarely repeat and hardly their processes either. Depending on the nature of the project, contextual variables, such as design team, location, budget, client, etc., affect the sequential and weighted priority of those variables. Awareness of this circumstance allows the comparison of the design strategy to functionality of tuning an (design) equalizer where each variable can be tuned up or down depending on their importance for the present project. Informed by the design equalizer's realization, the current project has classified the variables into separate task-flows where necessary. Within the BIM environment, these tasks are parametric modeling, analysis and linking them up in a loose relationship that allows relocating attention depending on the project needs.

1.6 Analysis Framework

Thecustom developed analysis framework's ray-tracing algorithm and geometry handler have been optimized for performance to potentially enable an iterative optimization loop. The kernel of this framework is a computational logic built on top of the lightweight spatial structure of a voxel definition. The aim of this framework is the rapid development of analysis algorithms that evaluate virtual models, visualizes concerns and opportunities, and enables a morphological responds within the BIM environment. Multiple criteria are identified and for each of these criteria, custom algorithms have been developed such as proximity, visibility, sky-factor, solar exposure, overshadowing, etc. The multidimensional voxel space enables to execute the algorithms simultaneously in order to create a composite picture. This allows the project to further develop into a multi criteria optimization framework.

The presented paper demonstrates on one case study the successful link of the developed analytical tools with the parametrically defined geometry values defined in the design models of the BIM environment.

2 Research Background

The creative relationship between designers and computers has been vibrant since the very beginningwith Direct Manipulation 1963, followed by End-User Programming 1980, Visual Programming 1988, Generative Components 2006, Model-Based-Programming 2009, and Design Script 2011. The trend of engaging with the computer as a design tool has been constantly raising up and current development projecting a tremendous impact on the architectural practice.

2.1 Design Stages

The architectural design and construction process has been organized by RIBA since 1963 into the “RIBA Plan of Work” [5] that presents a publicly available, standardized framework. The aim has been, to explicitly present the architectural process with its stages and responsibilities, reflecting the best practice as well as the underlying managerial structure.

In recent years the conventional plan of workhas been challenged due to the increased demand for rapid decision-making in the early project phase.New technologies and processes, such as BIM have disrupted the AECO industry due to its integrated design approach [6] that suggests a Lean BIM process [7] towards better performing buildings. The integrated approach implies that more information has to be processed early on in the design stage. This puts pressure not only on the design team, but also challenges the “Plan of Work” in respect of fee structure, contracts and responsibilities. As a result the time needed for analysis, evaluation and transformation becomes critical, and therefore needs attention.

2.2 Workflow and Data Communication

“RIBA Plan of Work” provides a good overview about the workflow during the design process. However with the adoption of BIM and the integrated approach to design, the traditional plan of work has experienced mutations. Due to the increased amount of data necessary for evaluation early on in the design, the method of communication has changed significantly. Two-dimensional snapshots of analysis results have been replaced by three-dimensional analysis results and they in turn are being replaced by four-dimensional simulation of analysis results. The new dimension will be the interactive and contextual analysis in real-time. From the perspective of exercisability, these changes have created a gap in the evaluation process. Tools provided by the major software vendors, such as Autodesk, Bentley or Graphisoft provide analysis functionality within their platform. There is however a barrier of accessing the result and using them to drive geometric transformation for form-finding. There is currently no commercial tool available to the industry that supports rapid analysis driven form finding.

2.3 Computational Design Tools

Software is generally designed to satisfy the conventional tasks of a specific user group. This software ideally provides a graphical user interface (GUI) to ease the use of its functionality. In creative industries, such as architecture, computer-aided design (CAD)systems present the software of choice to support conventional tasks. In recent years however, the complexity of tasks increased and non-standard became the new standard. The use of complex geometry or the need for a more efficient workflow has created a demand for a new kind of software and “computer programming to have more capabilities and freedom to explore design options”[9]. Nowadays, most CAD packages provide programming interfaces and organizations such as Smart Geometry are hosting workshops and conferences that focus on applying computing on real-life problems. Many websites and blogs emerged with user groups that share their experience, such as design-reform, Digital-Crafting, designplayground, etc. The tendency to improve design thinking and design support using computational tools, has become generally accepted and a vibrant area for design research.

Great attention is placed on the increase of functionality of off-the-shelf software that has provided some powerful tools to enable parametric modellingand analysis. Semi-open development platforms attached to CAD packages such as Generative Components, Grasshopper or Dynamo allow for advanced process thinking. Open source software development platforms such as processing.org have been adopted in parts to quickly explore computational algorithms and simulation ideas, but demand rather high programming skills.

The problem at hand is yet, that architects are generalistsand lacking the specialist’s knowledge, and time to deal with new computational technologies. Traditional design and workflow pattern are challenged.

On the other hand a new niche market emerged that specializes in complex geometry, BIM, digital fabrication and other design related technologies. New genres of practices have been formed to aid the industry with their design processes and computational support systems. To name a few that have sprouted up in the last few years are Evolute, Case, sliderstudio, etc. that provide specialist know-how regarding technology, geometry, management and design. This trend shows the increasing gap between design practice and technological demand and risks a disjoint of design and production. The presented research contributes to a possible resolution of this situation as discussed in the case study.

3 Research Method

The presented research is centered in the architectural design field and thus aims to balance qualitative, quantitative and experimental research methods that merge during the case study stage of the project as highlighted in Figure 2 [10]. The research focuses on practical and goal oriented exercisability that includes at its core the user as a qualitative variable. In an effort to support the user's decision making process, correlative research methods as part of qualitative research have been adopted. Correlative research is applied on a quantitative level used during the process of defining the types and combinations of analyses and subsequently on defining the relationship between their variables evaluated by their effects.

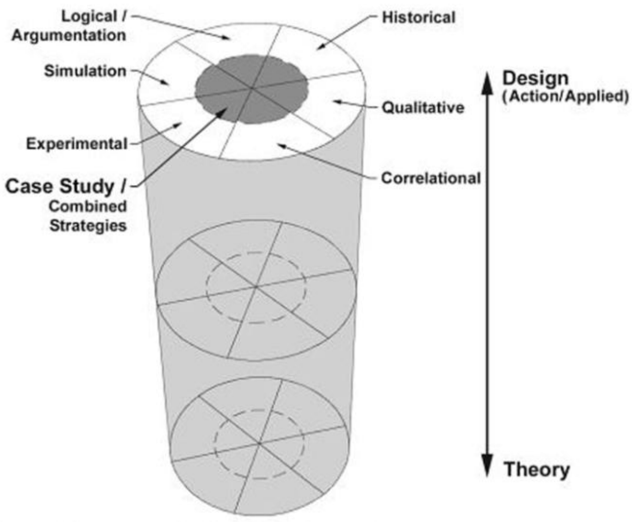

Fig. 2. A conceptual framework for research methods. [10]

3.1 Literature Review

The transformation from the traditional design operation to computer aided design operation has been scrutinized. The historic development of integrating computational means in the design process has been studied. The current development in visual programming has been evaluated and special emphasis is placed on linking them to parametric components in building information models.Primary research materials are taken from online conference proceedings, journals, articles. The target audience for this research paper is applied computational design research. In section six, all referenced material is cited.

3.2 Application

The ultimate goal of the presented project is to develop a framework for self-aware parametric BIM components that adopt within a simulated environment to contribute collectively to improve the performance of the virtual building design.Building on top of the initial research stageof constructive diagrams [11], the current research stage aims to establish a prototype workflow to test the functionality and applicability during the design process. The current stage also tested the link between the parametric BIM component and analysis data to trigger transformation.

3.3 Synthesis

Following the previous research stages, the current stage has established a working prototype that links analysis and transformation and thus closes the loop between context and form. The term context is rectified due to the chosen analysis type of a solar exposure that changes based on the provided context model. The major contribution consist of a C# analysis framework based on ray-tracing that is access from Dynamo via Python. Dynamo allows linking the analysis results directly into a parametric component in Revit, as described in more detail below.

4 Case Study

The presented case study aims to contribute to the subject of analysis-driven-form-finding. In an attempt to demonstrate the framework’s capabilities an urban scale analysis, paired with a small scale shading device responding to solar exposure has been chosen.

4.1 Workflow

Analytical analysis is becoming a standard procedure during the design process in order to guide the design development toward a well performing project. These analysis tend to generate colorful representations that in turn represent numerical values. Increasingly, these analysis functionalities are provided within the CAD/BIM package used by the architect as part of the integrated design approach. In order to be practical beneficial, the user has to be able to visualize the results, navigate and access the data, and use them as input for the next design iteration that improves the performance. Currently, there is however no off-the-shelf tool available to feed the analysis result directly back into the geometry.

The choice of developing an approach that links a building information model with an analysis algorithm via a visual programming interface lies in the necessity of being close to the tool of choice by the architect. The visual programming environment allows an expert analysis algorithm to access the model provided by the architect without affecting the architects behavior and design habits. In essence the architect would develop a parametric BIM family and defines the parameters to be changed by the analysis. The analyst would run the analysis and the team would see the BIM family adjusting. This provides a visual feedback and a numerical feedback that helps the design team to refine and optimize their family until the visual and numerical feedback from the analysis is acceptable.

4.2 Approach

In the following the operational sequence of the developed framework is provided.The initial input is provided by the design team in form of a Revit massing model that will be used as context for the solar exposure analysis.The massing model is loaded into dynamo, and the bounding box of the model is extracted. Within the bounding box the space will be subdivided into voxels that are scalable. The voxels within the massing model will be eliminated to reduce the amount of computation later on. The remaining voxels are saved as vertex list and visualized in the watch 3D node inside Dynamo. At this point it is important to mention that all the heavy computation is done in dynamo and only the results are exported to Revit due to Dynamo’s powerful geometry library. In the next step the massing model will be optimized, describing the geometry as a light weight vertex list. The site location provides the solar position during the day and year that are extracted from the weather files in form of a vertex list defining vectors. The ray tracing algorithm is developed in C# and is accessed by a Python node inside Dynamo. The Ray tracing algorithms uses the solar vertex-list, the voxel vertex-list and the massing model vertex-list as input and returns a list of values that match the voxel vertex-list IDs. The analysis output can be visualized via a watch2D node in Dynamo. In the following step the voxel vertex list will be sorted according to the analysis values and linked to a slider-bar. Operating the slider-bar will switch on or off the selected range of voxels linked to the values. This step is visualized via watch3D node (Fig 3). At this stage the nodes are not applied to a color range to match the values, but will be integrated in the following version. Alternatively Revit’s AVF – Analysis Visualization Framework was used to apply the color range to match equivalent analysis representations. Finally, via dynamo the parametric Revit family is selected and its parameters are extracted. The parameters are adjusted according to an upper and lower bound transformation rule to avoid breaking the family. After the parameters are adjusted each instant of the family is places in the designated position within Revit. For each iteration, the families will be updated.

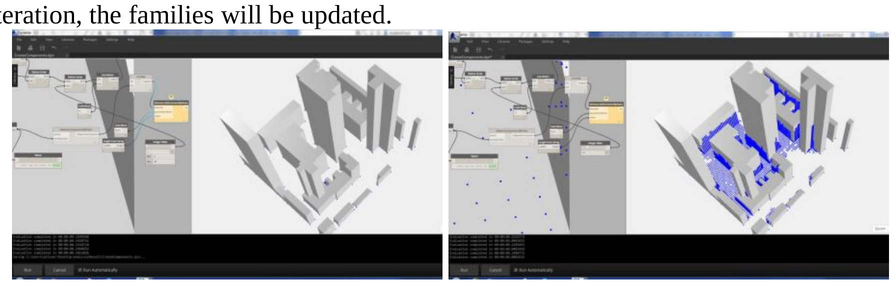

Fig. 3. Dynamo Interface and Blue Analysis Grid on context model.

4.3 Application

The framework has been applied to an urban analysis project in Hong Kong, in a small neighborhood called Sau Wah Fong in Wan Chai. Due to the site’s opportunity for pure pedestrianized street activity, the project team has investigated the potential to increase the zones for human comfort on street level. Due to the climatic circumstance in Hong Kong, the initial target was Solar Exposure or also called direct sun light.The goal was to provide shading for the street level during the hot and humid periods of the year. A light weight canopy is proposed that is covered with Chinese Lanterns’ like components.

The initial step was to define the site location and extract the solar positions from the weatherfile. As benchmark for the analysis, only the hottest day of the year was chosen and the exact sun vectors are extracted and stored in an excel file.

In parallel, the team has generated a 3D context model, based on the Hong Kong Digital Map. In order to simplify the complexity of the context model, a 1m grid approximation has been chosen.

Together with the Chinese Lantern Artist, the geometry of the shading device has been developed. Special attention was placed on the rationalization for the subsequent fabrication of the lanterns. The BIMer has set up an adaptive-component-generic (Fig.3) within Revit and focused on reducing the necessary geometry to a minimum. The parametric family is based on a box with three profiles, whereby the middle section is used for parametric transformation. The upper bound and lower bound transformation rule was set to strategically as normalized value between zero and one, along the edge length of the box. That way the family avoids a faulty state and failure.

The team has then identified a layer within the model that is located on an average Podium level of twelve meter. This level was chosen to receive the analysis values. The following steps to complete the analysis to transformation are already outlined in section 4.2 Approach.

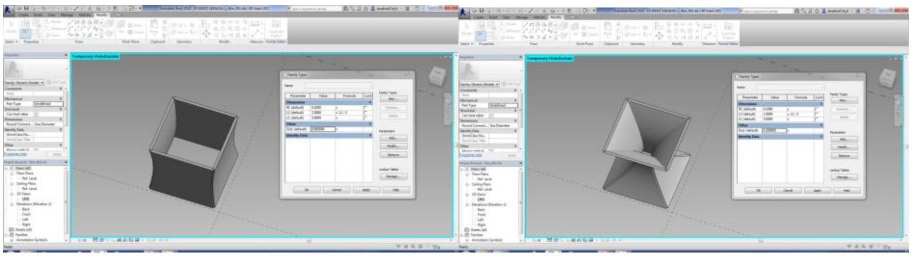

Fig. 4. Revit Generic Model Adaptive.

5 Conclusion

The conducted research presents the second stage of a five stage research.The initial first stage was focusing on developing and applying the concept of Constructive Diagrams with a BIM environment. In this current second stage, the constructive diagram approach was exercised and extended with parametric BIM families that transform according to values derived from a solar exposure analysis.

Three aspects of the second research stage have been developed, tested and evaluated. The first part of the project was the development of a light weight parametric BIM family that provides one parameter that responds to the analysis values. For this part it can be concluded that the standard best practice modeling method for parametric families can be kept. The only aspect to pay attention to is to constraint the degree of freedom for the parametric transformation. A lower and upper bound has to be identified in which the value can adjust. This definition has to be communicated to the second part of the project, the Dynamo link.

Dynamo provides a visual programming environment that is capable of operating stand alone as well as linked to Revit or Vasari. Within dynamo, the import, export, etc. structure is set up. The key elements within the Dynamo structure are the Family loader and the family's parameter loader. Currently there is no mean to inscribe the upper and lower bound definition within the family and thus has to be set manually inside Dynamo. The other key functionalities are the import of solar vectors and setting up the voxel space. Both are fairly straight forward. The main analysis functionality is written in C# in Visual Studio and accessed from Dynamo via a Python Node. This enables an optimized algorithm and also provides the flexibility to replace the algorithms easily without the need to access Revit or Dynamo. This clean split of tasks within this setup has been proven to be suitable for the dynamic design process.

The whole process operates rather smoothly within Dynamo. However, when writing geometry to Revit, the process slows down due to the number of used Revit family and itsheavy nature. The geometry kernel of Dynamo seems more powerful and lightweight compared to the Revit geometry classes and thus operates on a higher speed. In this respect further research has to be conducted to better understand the bottleneck within Revit.

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