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Connecting people and algorithms – Generative Design for informed decisions

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Learning Objectives

- Choose and formalize goals and constraints for a project
- Enrich an initial design proposal by using algorithms
- Compare multiple design alternatives based on high-dimensional, correlated design criteria
- Integrate a generative design process into Revit process.

Description

This is the story of our approach to generative design at Bonava. We will share our experience from how we developed our tools with starting point in the organization to the way we are working today. The focus of the presentation is on how algorithmic thinking can be used to help people take better decisions and understand and communicate what we are building.

It is one thing to develop a tool, but to change the way we think about the design process is something way more. To utilize the capabilities of today's computational power we need to not just write an algorithm but connect it to the way we are working by making it help us take informed decisions. That is when we have succeeded to connect people and algorithms.

We will also talk about how we want to move forward and what challenges and prospects we see in the future and our take on how AI will influence the industry.

This presentation aims to inspire and give some relevant insights and conclusions on how generative design can be implemented in an organization as a useful tool.

Speakers

***Sofia Malmsten** – Computational designer graduated from Chalmers University of Technology with a master's in architecture and Urban design and a Bachelor of science in Architecture and Engineering, focusing on computational design and how to assess architectural qualities in digital realm. Sofia is a consultant for Bonava, developing tools and processes regarding Parametric and Generative Design as well as digital workflows. With a background in programming and architecture she combines algorithms and design logics in order to investigate wide design scopes and enable data driven decisions.*

***Erik Forsberg** – bachelor's degree in architecture and Engineering from Chalmers University of Technology. He is currently studying a MCs in Complex Adaptive Systems and writing his master thesis at the Physics department where he wants to explore the possibilities that machine learning can open in architecture. Erik is especially interested in the way big quantities of data can be processed and used to understand what, how and why we build.*

***Anita Apele** – BIM Specialist, graduated from Riga Technical University with master's degree in architecture. Professional experience as an architect in residential field now is now brought to building information modelling, with the goal to eliminate as many mundane tasks as possible.*

Introduction

The Bonava way of thinking

Bonava is a leading residential developer of affordable housing units in Northern Europe, operating in eight countries around the Baltic Sea. Born out of NCC, of Scandinavia's biggest construction companies, we have been creating homes and neighborhoods since the 1930s.

Our goal is to build affordable homes where people can have the highest quality of life. To do so, lowering costs and increasing productivity is essential. Standardized single family houses has been developed, and with that also models, drawings and documentation in Revit. By standardizing the core components of the houses info a handful of different types we have reduced the complexity for how we build our neighborhoods, but the number of ways we can develop a site is still much larger than what's possible to explore manually.

This has brought us to exploring the possibilities of generative design and how it can be applied to different types of projects. For single family housing the site design remains the largest variable. We use generative design tools to create more detailed site layout solutions in the early stages, and measure both hard and soft values for each option.

Design exploration now is backed up by numbers and it gives us the possibility to see correlation between different design metrics. This allows us to bring representatives of different disciplines to fact-based discussion early in the project to assess the plot and take informed decision for further development.

Two of the key concepts for the way we chose to work with generative design at Bonava is the Virtual Design and Construction team and Bonava parts. We will give a brief introduction to these concepts before we continue.

VDC

Boniva's Virtual Design and Construction (VDC) Program is part of our strategic initiatives that started in 2016 to transform our business in order to meet the demands of a new generation of digital customers. It has the support of the Executive Management Group as well as every Business Units Management teams.

For Bonava, the implementation of VDC is an important step towards changing the housing game and creating better homes and lives for the many. It directly supports our work around Improved efficiency and Shared processes and systems, supports our initiatives to reduce costs and increases differentiation through customer focus.

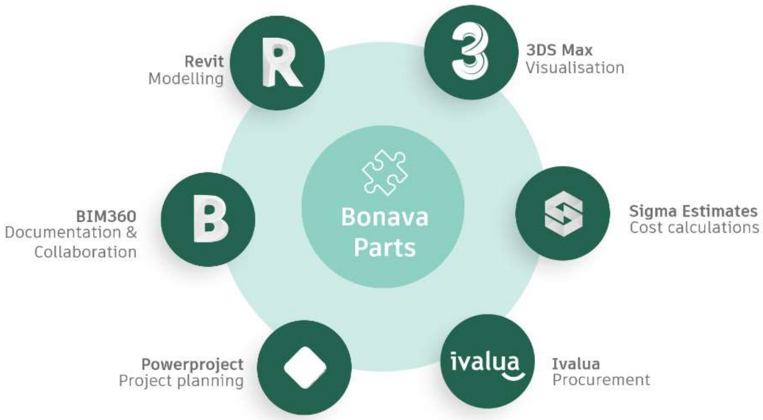

FIGURE A: SOME OF THE VDC SOFTWARE THAT ARE USING BONAVA PARTS.

Bonava parts and the Building system

A Bonava Part is a key element that is used in all processes from modelling to cost calculation, production and visualization. The part is predefined and can be used over and over in many different projects and it contains rich information about its technical specifications. It can be in many different scales as well, from a door handle to a whole house. One could say that it is a clever Revit family that has a lot of useful information attached to it!

A building system is a collection of Bonava parts that also contains a complete a complete description of coordinated technical solutions that enables execution of design and production phases of the Building Projects.

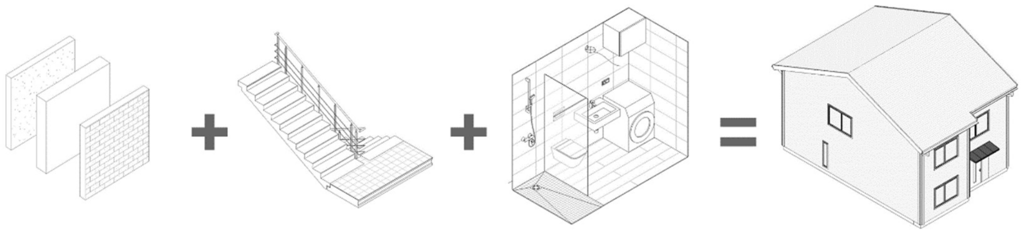

FIGURE B: THE BUILDING SYSTEM IS A COLLECTION OF BONAVA PARTS TOGETHER WITH A DESCRIPTION OF HOW THEY RELATE TO EACH OTHER IN A SPECIFIC EXECUTION.

Choose and formalize goals and constraints for a project

The first step in using generative design for a project is to formalize the goals and constraint for the project. This is what we call the setup phase, and it consists of gathering information from multiple different sources and combining them into rules that can be applied when generating alternatives. To make it easier to understand each individual requirement, we have divided the input to the project into three distinct categories.

Bonava parts

Since the parts themselves are already defined, we can use them as the starting point for all our design process. In the single family house setting we have for instance exact dimensions for all houses and these values does not change between projects and can therefore be kept as an "automatic input" that only needs to be changed when something is updated.

What needs to be chosen though is which Bonava parts should be used for a specific project and their interface. Do we want to use all out-house types or only a few? Should some of the houses have carports? Do we want to have long house rows or freestanding houses?

Multiple different variations can be tested and evaluated for a single project, but we have fund that it is a good idea to discuss what we want to achieve in the project and specify some basic rules based on that before we start generating alternatives.

Plot

The specific site where the project is located can give us useful information of how the project is best executed together with requirements that needs to be fulfilled. We look at GIS-data together with a topography model to get a better understanding for how the project should be setup. Some sites already have an existing street networks and in some other cases it needs to be built which as well gives the project a new level of complexity and a much wider range of possible outcomes.

Some parts of the plot might be unsuitable for building due to being steep or having other restrictions. We try to locate these areas and give it as an input to the generator to avoid creating alternatives that cannot be built.

Restriction and requirements

Restrictions and requirements can be things such as national building requirements or fire- and accessibility regulations. We want all the solutions that are generated to be possible to build with only minor changes so based on where the project is situated we give the relevant rules as an input to the generator to avoid creating unfeasible alternatives.

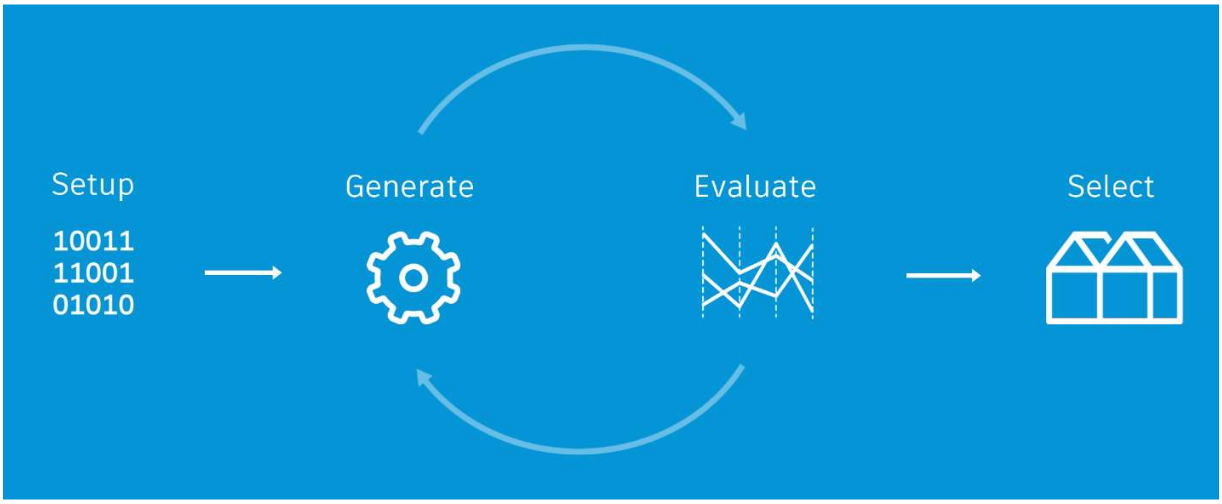

FIGURE C. THE GENERATIVE DESIGN WORKFLOW AT BONAVA.

Enrich an initial design proposal by using algorithms

The single family house algorithm

The algorithm for generative design of single family house neighborhoods that we have developed is based on fixing some parameters (such as the houses themselves) and exploring the space of possible design solutions by tweaking other free parameters. An impressive amount of variety arises from every parameter that is left free and the result is a rich set of combinations with varying features.

The algorithm is a so called procedural algorithm that bases the next part of the generation partly on the outcome of the previous. One of the advantages of generating using this algorithm structure is that we can save an alternative in what part of the generation we want and continue from there to create more possible outcomes. If we for instance find a really good solution to the street network layout, we can create hundreds of options with that precise street configuration to investigate that exact corner of the design space in detail.

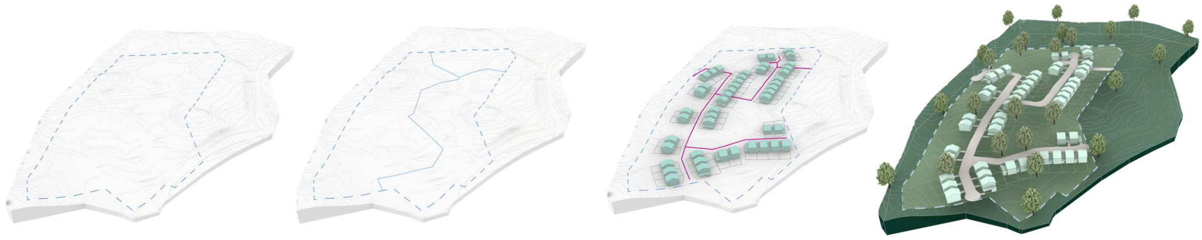

FIGURE D: SNAPSHOTS FROM DIFFERENT STAGES OF THE PROCEDURAL ALGORITHM THAT IS USED TO GENERATE DESIGN ALTERNATIVES IN THE SFH SETTING.

Multi family house algorithm

The multifamily house generation algorithm is quite different form the single family house algorithm, although the underlaying principle is the same. The starting point is once again the set of Bonava Parts. By applying interface rules between the parts, we can create a much bigger set of possible living units with different qualities. These living units that we create should not be seen as the final design, but rather a quite sophisticated layout graph that captures the main features of the apartment and what Bonava Parts are needed for that specific configuration. We save these draft apartments to a database and they can then be used as starting points with partly known qualities when designing a new project.

The draft apartments cannot be fully evaluated since some properties are dependent on the specific location position for where they are placed, but other properties, such as material consumption and shape factor, can be evaluated directly when the apartment is generated. By using these metrics, we can get a proxy for where the project will go in terms of these KPIs.

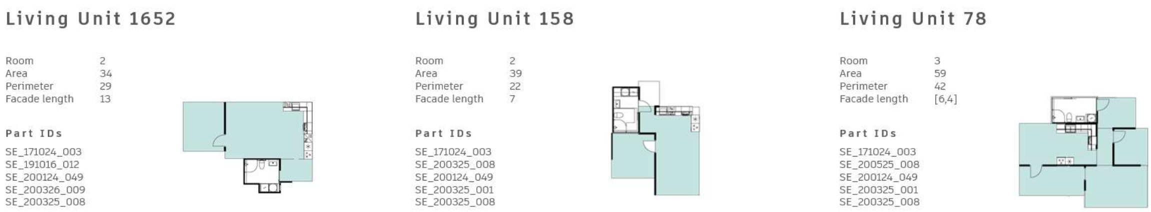

FIGURE E: SOME OF THE GENERATED DRAFT APARTMENTS THAT ARE SAVED IN THE DATABASE.

Compare multiple design alternatives based on high-dimensional, correlated design criteria

To be able to know what alternatives we want to develop further we need a way of evaluation and rank them. Every alternative that is generated is at the same time evaluated based om a set of criteria and their score is saved together with the alternative to a database.

Design explorer

It's not only absolute numbers for each alternative score that are of interest, but also how they relate to other alternatives. To be able to see and compare multiple alternatives in simultaneously we use a parallel axis diagram where each evaluation criteria is represented by a vertical bar and the score is where the curve corresponding with the alternative intersects the bar. This data representation makes it easy to compare many multi-dimensional data points, and it also makes it possible to draw conclusions of correlation between parameters. The data for each parameter is also properly normalized to make it easier to compare aspects with widely different units.

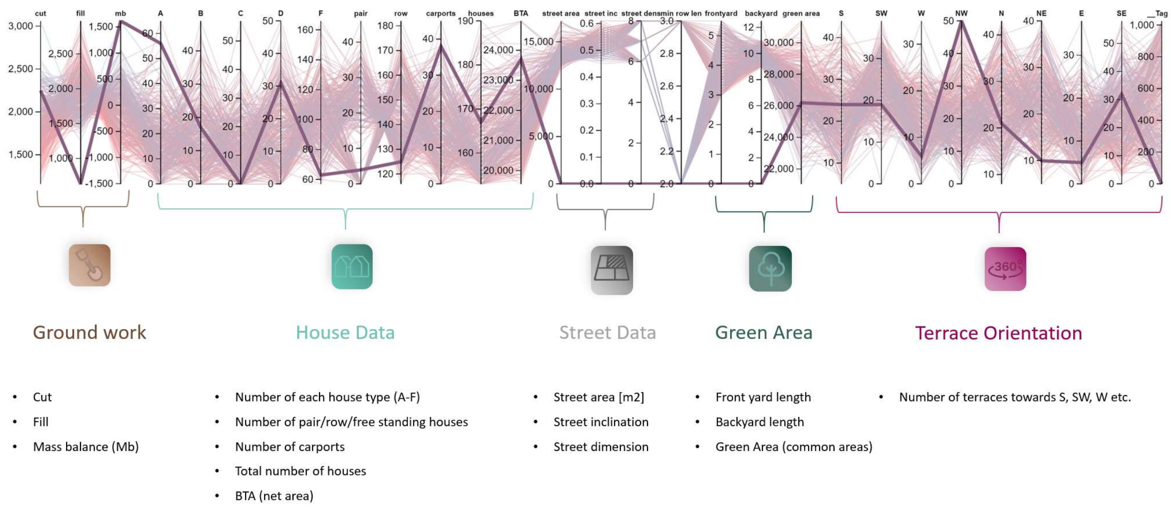

FIGURE F: SOME OF THE EVALUATION CAPABILITIES AND THEIR CORRESPONDING CARDS IN A PARALLEL AXIS DIAGRAM.

Evaluation capability cards

To make it easier to know what types of evaluation we are capable to perform and how these relate to each other, we have divided them into categories. Each category is represented by a card an all parameters inside that category deals with similar types of data. This makes it easy for the project team to choose what criterion they are interested in evaluating since they only need to pick the cards that are relevant, and they will include all necessary parameters in that category.

We always try to break the evaluation criterion down into as elementary parameters as possible. We have for instance no one parameter that estimates the total cost of the project, but this is rather broken down into the components that drives the cost such as the amount of groundwork and how many houses we end up building. The reason for this is that it give us freedom and flexibility to calculate more sophisticated metrics based on the simpler parameters without sacrificing any generality.

FIGURE G: THE EVALUATION CAPABILITY CARDS.

Integrate a generative design process into Revit

Revit is the main design and documentation tool that we use at Bonava and it's also where the Bonava Parts primarily live. Therefore, it's key to have a solid integration between Revit and all other processes we have in the organization, whether it's visualization, cost calculation or generative design.

The dataflow

The geometry and metadata for the Bonava Parts are all defined as Revit families, so that's where the project is set up. The generation is done inside Rhinoceros 3D and the geometry and corresponding evaluation data is pushed in .json format to a Mongo database. The evaluation data and a picture representation of the alternative is visualized using the open-source web tool Design Explorer. Each alternative gets an alternative id that works as an unique identifier for the alternative both in Design Explorer, but also when importing the alternative into Revit.

Since the Bonava Parts are pre-defined the only thing that needs to be stored to be able to recreate a specific alternative is the parts' position, orientation and unique identifier. This makes the dataflow very efficient since it is a really small amount of data that needs to be saved compared to the actual geometry of the whole alternative.

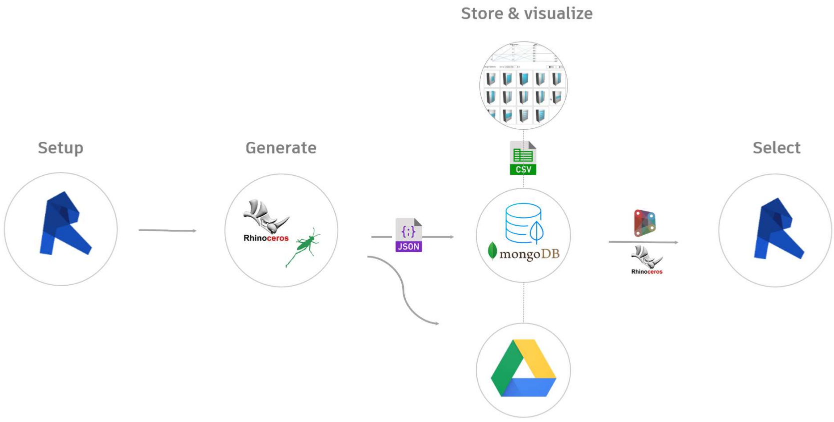

FIGURE H: A SCHEMATIC DATA FLOW DIAGRAM OVER THE GENERATIVE DESIGN PROCESS IN BONAVA.

Importing into Revit

When a set of alternatives that we want to develop further is chosen, a custom script is run in a Revit file with all the necessary Bonava Part families loaded. The script brings up a window that works as the interface between the database and Revit. In the window the user logs in to the project with a special username and password and can then read the data. The chosen alternative is first visualized in 3d in the window together with some metrics. If the user is happy with the alternative, he or she can click on the Revit button to bring the alternative into Revit and continue developing it there.

What really happened is that the parts that are loaded into Revit as families are being placed on their respective position according to the alternative. Since all the families are already loaded into Revit, the action of importing an alternative is much quicker that what it would have been to generate all the geometry from scratch.

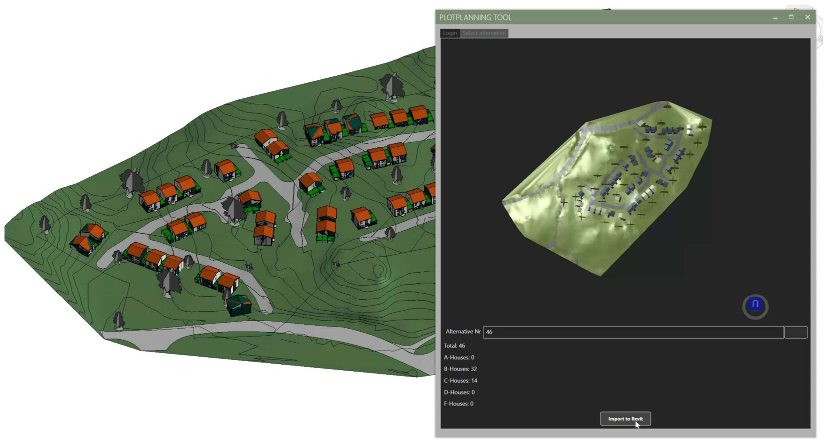

FIGURE I: THE INTERFACE BETWEEN REVIT AND THE DATABASE. THE SCRIPT TO ACCESS THE IMPORT WINDOW IS RUN FROM INSIDE REVIT.