

Performance-Based Design Strategy and Parametric Design Goal Setting

Advanced approaches to performance-based design are fundamentally different from conventional CAD simulation processes. .

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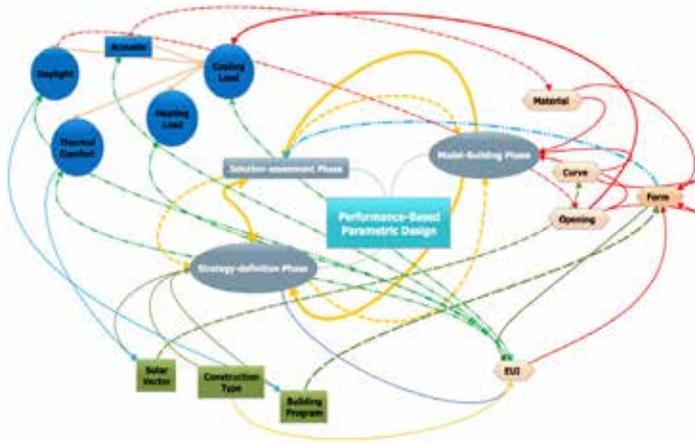
INTRODUCTION

Carbon-Neutral Building is not an idea for the distant future; it is an idea whose time is now. We have the technology and the knowledge to deliver net zero energy commercial building today. What we lack, more than anything, is the collective imagination to make it happen. The imagination lies on new type of workflow and the transformation between traditional building system knowledge and advance computer modeling ability.

In traditional architectural practice, the effort invested to integrate performance measurements in the conceptual design phase is usually very limited. This attitude is not consistent with the unanimous importance attributed to the conceptual design phase, where the most influential design decisions are taken. Specifically, exploring different design alternatives is commonly recognized as crucial in conceptual design.

Performance-based design may be generally considered as an approach in which building performance becomes the guiding factor in design. Performance-based models in architecture may be defined as the exploitation of building performance simulation for the modification of geometrical form towards the objective of optimizing a candidate design. Building performance has long been recognized as an important issue in architectural design, and has long been considered a seminal component in the value-system of architectural design.

Advanced approaches to performance-based design are fundamentally different from conventional CAD(Computer Aid Design) simulation processes. Traditional simulation tools are premised upon the ability to simulate and evaluate performance of the object itself once it has been defined at an appropriate and desired level of resolution. Thus they are rarely employed in early conceptual stages of design. Current technologies are, to certain extent, capable of the integration of design synthesis formation processes that are directly informed by performance-based simulations.



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Structuring the parametric geometry in relation to information on various performances is crucial. Failing this would mislead the entire process and possibly generate unsuitable outputs. In this paper, the author describes and exemplifies alternative approaches and presents them within a theoretic framework. The different approaches relate to different levels of knowledge that concern the performances considered in the process and which are available to the designer while the parametric model is being set. This paper focuses on the quantifiable performance aspects of design requirements. However, quite a number of requirements are quantifiable, even more when considering that also linguistic architectural choices are mostly translated into the control of physical phenomena.

PERFORMANCE-ORIENTED PARAMETRIC DESIGN

Parametric modeling represents geometric entities having editable attributes, and relationships by means of associations. Attributes can be expressed by independent values, which act as input to the model; their variations generate different solutions of the model. The ensemble of these alternative solutions is named the solution space of the model. The process in which the editable attributes and the associations are set is named the parameterization process; and it usually outputs a hierarchical structure describing a dependency chain. Overall, parametric modeling is a goal oriented process that requires the exploration goal to be properly targeted in advance. The goal-oriented nature of parametric modeling is crucial when dealing with performance-based design.

The Three Phases of Parametric Performance Oriented Design

Focusing on the conceptual stage of performance oriented design, the use of parametric modeling involves three phases, in which the expertise and knowledge of the designer is required to meaningfully address the process. During the first phase, strategy-definition, the parameterization process is addressed based on the analysis of design challenges, abstraction of relations between performances and geometry, and formulation of parameterization strategies according to the design intentions and selected performances. During the second phase,

Figure 1: Workflow Diagram.

model-building, the parametric model is constructed according to the logic that emerges in the first phase. During the third phase, solution-assessment, the design alternatives embedded into the parametric model are explored based on performance evaluations.

The strategy-definition phase depends on the need to define the hierarchical associations based on the explicit representation of a design strategy. A design strategy can be developed through analytical investigation of geometric properties in relation to the design requirements. Once the design requirements are captured and rationalized, the geometric properties that affect their satisfactions can be made explicit. These properties address the focus of the parameterization. While formal frameworks exist for identifying, capturing and managing design requirements and methods for decomposing requirements, there is a lack of support for relating requirements to the geometric properties of the design. Design Scenarios offer extensive support in formalizing the process, including the annotation of variable parameters that impact the design requirements. However, the identification of such parameters is left to the multidisciplinary design team and is not specifically addressed in the framework. Nevertheless, the process in which decomposed goals are related to the decomposition of geometric design properties can be formalized in relation to the analysis for performance evaluation.

The formalized process distinguishes four steps. In the first step, given a design concept and (quantifiable) design requirements describing the desired performances of the project, preliminary numeric analysis are run on a reference geometry to identify and quantify the level of the eventual missed fulfillments (for example: achievement of thermal or daylight comfort). During this first step, preliminary understanding of challenges and potentials to reach the design goals are identified. In the second step, based on the previous results, the specific sub-goals are established, which decompose the design requirements into more specific tasks (for example: reduction of summer overheating or of light contrast). The output of this second step consists of the list of sub-goals. In the third step, various design aspects are analysed, searching for the ones favoring the achievement of the sub-goals (for example: increasing thermal mass or reduce direct light transmittance). The impact of the design aspects can also be further verified by means of preliminary numeric analysis. The output of this third step consists of the list of properties of the primary generator that impact the achievement of the sub-goals. Finally, in the fourth step, geometric properties are extracted for the aspects having positive impact on the goals. These geometric properties are the ones to be parametrically investigated; therefore, their attributes are parameterized. The list of these geometric properties and their attributes is the output of the strategy-definition phase. Based on the so established parameterization strategies, the parametric model can be built (model-building phase). Subsequently, the solution-assessment phase concerns the evaluation of different design solutions in search for well performing instances or even carbon neutral solution (desired solution space) among the ones embedded in the parametric model (actual solution space). This exploration can involve different methods, mainly according to the breadth and meaningfulness of the solution space, both of which depend on the strategy-definition phase. This aspect is discussed below.

Relations Between Strategy-Definition and Solution- Assessment

The three phases of parametric performance-based design are not linearly dependent, but directly interrelate with each other. The interrelations between the performance-based parameterization in the strategy-definition phase and

the performance-based exploration of the solution space in the solution-assessment phase are particularly important, especially concerning the meaningfulness and the breadth of the solution space.

The meaningfulness of the solution space indicates that the instances are expected to express a meaningful range of variations on key aspects affecting the analysed performance. This is needed in order to successfully explore the solution space for identifying well performing solutions. Since different independent parameters and hierarchical associations (in other words, different outputs of the parameterization process) identify different solution spaces, the meaningfulness of the solution space depends on the parameterization and, therefore, on the strategy- definition phase. Also the breath of the solution space depends on this phase, because it is determined by the number and ranges of variable parameters. The breath can be calibrated depending on the knowledge available to the designer during the parameterization process. Sufficient knowledge may prevent the exclusion of meaningful solutions when relations between geometry and performance are uncertain. Additionally, the more knowledge is available during strategy-definition, the more the actual solution space can be made to coincide with the desired design solution space and the need for analyses during solution-assessment can be reduced. As an extreme case, formulating a deterministic relation between the variation of the geometric attributes and the performance trend allows a coincidence between the generated instances of the model and the well performing configurations.

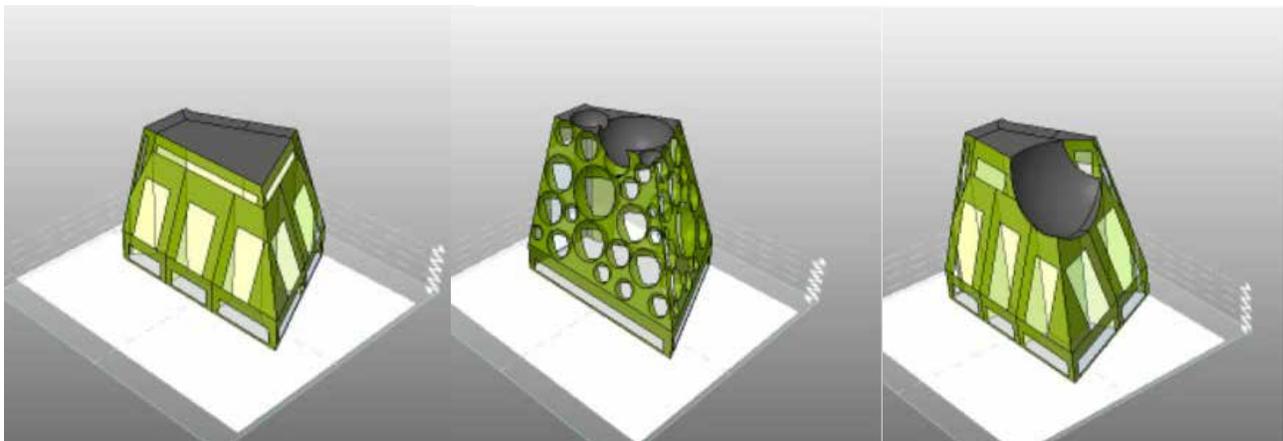
CASE STUDIES

In this section, three case studies are discussed, focusing on the relation between the knowledge available in strategy-definition and the exploration occurring in solution-assessment. In the first case study, a process is presented in which only a few relations between geometry and performances were formulated; as a consequence, the parameterization broadened the number and range of parameters, enlarging the solution space of the model. In the second case study, the knowledge available during strategy-definition was also initially limited, but different ways to increase the knowledge in this phase were explored. Specifically, analytical numeric calculations were joined with physical measurements and testing in order to gain knowledge and extract the meaningful geometric parameters, and therefore narrow the solutions space. This process is discussed in terms of an iteration relating the different phases. In the third case study, this process is further developed, until it allows the definition of a deterministic relation between performance and geometry.

Case Study 1: Large Solution Spaces

The first case study presents a process where the identification of well performing solutions relied mainly on the solution-assessment phase, investing far less effort in the strategy-definition phase. It concerns the design of a visitor center by students. Of the overall design process, only the aspects concerning overall conceptual energy consumption and daylight intensity are presented here. The different design options all share same set of building system setting, such as HVAC system, air change rate, construction type. The massing of the visitor is intended to take advantage of the site condition and local climate characteristic. The primary geometric generator is the building energy utilization intensity. Having defined the primary generator, the student limited the strategy-definition to a preliminary analysis (using Autodesk Vasari) to generally determine which variables to consider and which limits to take into consideration. Meaningful

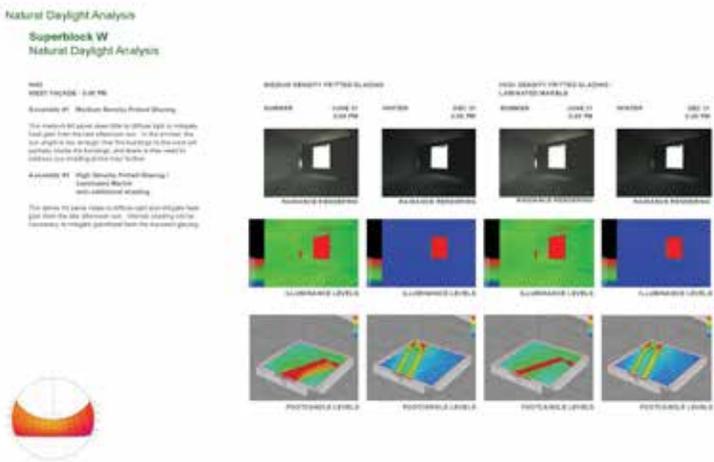
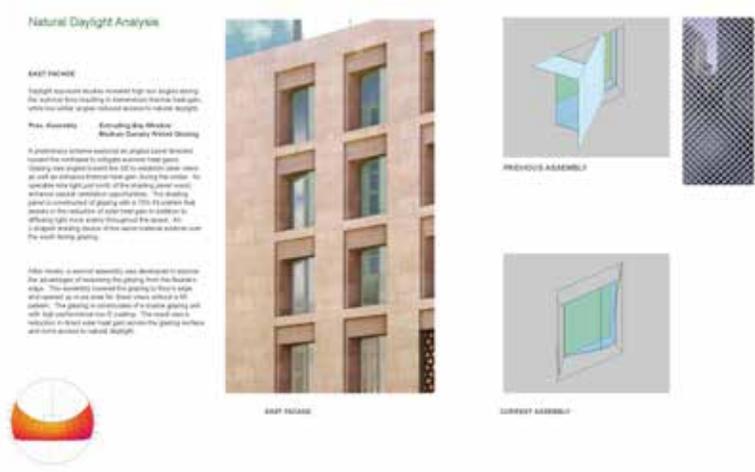
relations with energy consumption were identified concerning the overall shape of the massing, the density (and therefore dimensions) of the components, the percentage of variable openings – a relation was formulated between the definition of the openings and the position of the sun – and other meaningful aspects were identified in non-geometric properties, such as materials. The parameterization for the model was set according to the geometric aspects to be explored, with the overall shape parameterized in order to achieve different curvatures, the density of the components based on their UV distribution, the relation with the solar vector based on an angle of tolerance, and the percentage of opening area based on various distances of offsets and heights of extrusions. The parametric model was built (model-building phase) and its solution space explored (solution-assessment phase). In order to search for geometric combinations having thermal comfort qualities with the desired effects, heating and cooling load simulations were made in Ecotect for a number of instances. Ecotect also allowed the investigations of different material properties on the same geometric solutions. No computational search techniques were coupled with the parametric model and performance evaluation software. In order to guide the search and reduce the number of iterations for evaluations, the evaluation process was subdivided into three steps: the effects on the heating load reduced, respectively, by the variation in the curvature of the whole envelope, the material qualities, and the percentage of closed/open areas in the components were tested separately.



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Despite the advantages of creating a large set of design alternatives to be analyzed numerically, two main levels of difficulties were encountered by the students. The first regards the parameterization process, which was based on intuitive conception and preliminary identification of relations between geometry and daylight effects. The second regards the selection of the instances to be evaluated, which was deemed to be the most challenging aspect, if performed without the use of computational search techniques. The high number of possible instances and the complexity of the geometry made the performance behavior highly unpredictable to the students. Despite the decomposition of the search process into three separate steps, the options to be evaluated were difficult to choose. The integration of further computational support for the exploration of design alternatives is confirmed as valuable with respect to this difficulty. However, the remaining case studies explore a different direction, consisting of increasing the analysis during strategy-definition in order to reduce the number of variables and increase the capacity to predict their influence on performance.

Figure 2: Case Study 1 - Massing Options.



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Case Study 2: Narrowed Solution Spaces

The second case study tackles ways to narrow the solution space by increasing the coincidence between the actual and desired solution spaces. It presents the Retrofit competition project for an office building. The part of the work presented here focuses on the design of the envelope for daylight performances. For each function daylight requirements were defined according to the building regulations, the design intentions and preferences between direct or indirect light, the level of acceptance for discomfort given by glare and required safety (for which glare could create risks). The overall configuration of the building was previously defined since it is an existing office building.

In contrast to the previous case study, four alternative primary generators were conceived for the envelope during the strategy-definition phase. Within this phase, initially, an early set of preliminary (non numeric) analyses were made on computer model. Based on their results, the four generators were formulated using the geo- metric properties detected as significant. Subsequently, more preliminary analyses ran transversally across the four primary generators, for each of which both physical and digital tests were made on partial models. The physical tests allowed collecting numeric data used for both a deeper understanding of the factors affecting the daylight performance and calibrating the digital analysis. Digital tests were run on multiple variations of the system. The process allowed selecting one primary generator (consisting of a diamond based grid) and its

Figure 3: Case Study - Lighting Study.

meaningful geometric factors. For these, two families of geometric parameters were identified, respectively controlling the horizontal and vertical inclination of the cladding elements. Based on the so identified cladding, the overall surface of the envelope was then tessellated. Additionally, a parameter concerning the material properties (translucency of the panels) was identified as relevant for investigation. The parametric model was built (model-building), and its solution space explored (solution-assessment) based on performance evaluations that were run for the different areas of the project, according to the different functions and daylight requirements. The geometric configuration and the materials chosen by the team to run the first analyses were assessed as relevantly close to satisfactory for the desired performance. For further investigation and possible improvement, tests on slightly adjusted parameters were recommended.

This case study shows the potentials of performing deep analyses in the preliminary phase of the process. They allowed the identification of meaningful geometric factors; they also allowed understanding and drawing a relation between the variation of the geometric factors and the performance trend. In this way, the geometric configuration set as first solution to be analyzed has emerged already close to the desired performances.

Case Studies 3: Deterministic Solution Spaces

The previous case study has shown how relevant a deep preliminary analysis phase is in order to meaningfully narrow the parametric solutions space to be further explored. The remaining case studies exemplify this attitude brought to its extreme consequences. In these cases, parametric modeling was used to explore a set of geometric variations only after the relation between the changes in geometry and performance trend was fully understood and mathematically expressed. As a result, the solution space does not contain alternative design solutions to be explored searching for well performing configurations; instead they represent one or more design configurations satisfying the analyzed design requirements.

The third case study focuses on acoustic absorption as a design requirement, with the aim of designing an indoor architectural product. The primary generator was defined by the designer only after the strategy-definition phase was finalized. This consisted of a relevant number of tests, which included conception and 3D-printing production of different prototypes embedding a number of geometric variations to study their impact on sound absorption. Only when clear principles were formulated, the primary generator was conceived and its parameterization process finalized upon the principles extracted during the tests. Guarantee of good performance is expected from the instances of the parametric model. The model acts in this case as generic design tool applicable in future projects, to parametrically generate different design solutions according to different acoustic conditions.

This case study exemplify an effective way to limit the parametric design solution space to a set of well performing solutions, to generate both specific configurations suitable for different designs, as in the case of the acoustic absorber. This approach presumes a preliminary solid knowledge and understanding of the analyzed performances and the possibility to formulate a relation between geometry and performance.

CONCLUSIONS

The paper presented and discussed the three phases in which parametric performance oriented design can be structured (strategy-definition, model-building,

solution-assessment); and tackled the interrelations among these phases, with specific emphasis on the relations between strategy-definition and solution-assessment with respect to meaningfulness and breath of the solution space to be explored. Three case studies were presented. The first case study focuses on large solution spaces; the second on increased performance analysis during strategy-definition in order to increase the correspondence between the actual and desired solution spaces, and therefore narrowing the actual solution space. The third case study focus on the full coincidence between the actual and the desired solution space, based on deterministic relations between geometry and performances, formulated either based on knowledge extracted during strategy-definition or on previously established knowledge. In conclusion, the choice the designer makes concerning the time and effort investment during the different phases and the awareness concerning the consequences of the attitude taken at the different phases of the process are essential. An absolute judgment concerning the right attitude to be taken is here avoided in favour of a choice that needs to be made according to the different design cases. The choice is especially dependent on the level of knowledge and understanding that is possible to be achieved in the strategy-definition phase within a reasonable time for the process. Ideally, a high availability and use of knowledge has to be recommended; and time investment could be particularly convenient when general knowledge useful also for future projects can be gained.