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PARAMETRIC DESIGN AS A TOOL FOR PERFORMATIVE ARCHITECTURE

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ملخص البحث
أدت الحاجة إلى البحث السريع عن حلول مبتكرة فى مجال العمارة إلى دمج تقنيات البرمجة فى عملية التصميم المعمارى من خلال ما يعرف بالتصميم البارامترى، وذلك بترجمة أهداف التصميم لمعادلات رياضية وعلاقات هندسيه، ذلك المفهوم فتح المجال لما يعرف بالتصميم على أساس الأداء، والذى يمكن المصممين من دمج تقييم أداء أحد متطلبات التصميم ليكون محر كا رئيسيا للعملية التصميمية واستغلال تقنيات التصميم بمساعدة الحاسوب كأداة لتصور شكل التصميم و الاهتمام بتلبية المتطلبات الجمالية والوظيفية للتصميم سواء إنشائية أو بيئية كالإضاءة الطبيعية والراحة الحرارية وغيرها. لذا فإن الهدف الرئيسى من البحث يتمثل فى توضيح مراحل التصميم البارامترى الاربعة و كيفية دمجه في العمليه التصميميه وتقديم استراتيجيه عمليه لاستخدامه فى التصميم.

ABSTRACT
Recently in architecture, the need for rapid automatic exploration of design solutions that respond to complex design requirements through coded systems using computation techniques led to the inception of what is called Parametric Design. It facilities the process of performance based design to integrate performance evaluation of a certain design requirement with optimization techniques to choose near optimum solutions and neglect the bad ones in early design phases affecting form generation. The main objective of this paper is to illustrate parametric design process which consists of four steps connected during conceptual design phase; Parametrization, Generation, Evaluation and Optimization, and enhancing performance in buildings.

Keywords: Parametric design, optimization, methodology, Performance based design.

1. Introduction
Recently there is a need for rapid exploration of unpredictable design solutions that respond to objectives such as aesthetic, performance, project requirements, site constrains and construction or the new demand of digital fabrication. This have recently led to the inception of what is called parametric design where the objectives are transformed to be the design parameters. In the contemporary practice Parametric systems are principally based on algorithmic codes which allow to express procedures for solving design problems.

Implementing Parametric Design facilitates the process of exploiting computational techniques to integrate a performance evaluation of a certain design requirement with optimization techniques to automatically generate and test different design solutions without the need to redraw each solution as in the traditional way of the architectural design process. Then, based on optimization criteria the near optimum solutions are selected and the bad ones are eliminated.

2. Parametric Design Process In Conceptual Phase
A computational framework for parametric design which is called a design procedure was

proposed by (Hernandez, 2006a). He proposed the design process as a procedure process, because in computation a procedure is a description of the steps necessary to accomplish a task. It is also used to perform specific functions. The geometry that describes a design can be also generated as the result of a script (procedure) or recipe that when followed step by step yields the same results. Parametric design process has been discussed several studies. It is incepted from a computational way of thinking to solve problems by dividing it into smaller problems. Parametric design relies on programming; however, it requires an extensive thinking to plan a design schemata to well exploit such approach. Therefore, parametric design process can be summarized in to four phase; Translation to Parametrization, Generation, Evaluation and Optimization as discussed by (ElSalam, 2010, Hernandez, 2006a, Hudson, 2010) as shown in figure 1.

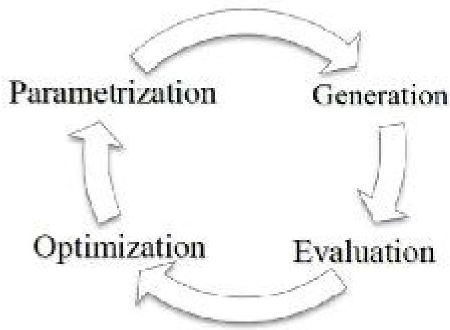


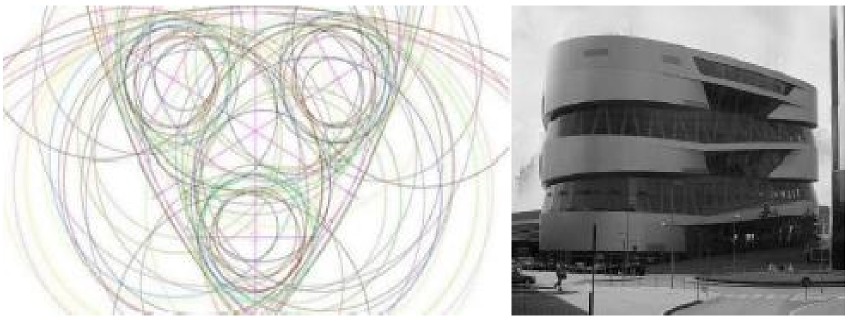
Figure 1: Chart to show the phases of Parametric Design process by researcher after (Hernandez, 2006a, Hudson, 2010, Oxman, 2008)

2.1. Parametrization

The designer must precisely study and understand the requirements of the design problem to produce one or more solutions and to test them against some explicit or implicit criteria (ElSalam, 2010). Then extract numbers, relations, shapes and operations that will be integrated in the design process. The process of defining the boundaries and constraints of an exploration helps to define the problem itself. The exploration of a design problem makes the designer aware of the limitations and constraints of a design problem (Kilian, 2006). This phase is a strategy-definition. It is addressed based on the analysis of design problem, abstraction of relations between performances, geometry and formulation of parameterization strategies based on the design goals and requirements regarding selected performances. 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. Identifying such parameters requires collaboration from the multidisciplinary design team (Hu, 2014).

This phase includes:

Translation	In computation, procedure is the steps necessary to accomplish a task. Therefore, the design objectives is translated in to a set of constraints and parameters as numbers or shapes, and a set of steps "algorithms" which are mathematical and geometrical relationships (Stavric and Marina, 2011). The parametric translation task is concerned with changing from a non-parametric representation to a parametric model. It requires an understanding of the problem or design task. This means knowing what is being investigated, what parts can change and what is fixed. Based on this the designer can start to create a model to capture the process (Hudson, 2010).

Rationalization	It is a critical part of the translation process. It is to define geometry with methods that create it. This is either applied early (pre-rational) or later (post- rational) in the design process. It refers to the application of known geometric principles and construction techniques to generate design solution. Post- rational is where geometry and construction constraints are considered after a conceptual design phase for example Norman Foster building of London City Hall as shown in figure 2. When geometric method is rational from early design stages it is referred to as pre-rational (Hudson, 2010)  **Figure 2: On the left is London City Hall by Norman Foster as post rational instance, and on the right is Swiss Re Building by Norman Foster also as pre-rational instance**.
Control	Setting the rules to be controlled by parameters is a crucial task. Geometric control is one of the primary tasks for the parametric designer. Control in parametric modelling can be considered on multiple levels. For instance, the control of plan form by DTP in 2008 for the definition of a parametric model for the Mercedes-Benz Museum as shown in figure 3. This plan arrangement consisted of circles, tangents and intersection points, these defined planar curves that set out constantly rising spatial curves which describe the building's three- dimensional form (Hudson, 2010). Control systems should be simple and intuitive allowing hand-eye coordination to define building geometry.  **Figure 3: On the right controlled circles, tangents and intersection points through a parametric model to generate Mercedes Benz (Design to production, 2015), on the left UN'Studio' design of Mercedes Benz through a controlled parametric modelling (Helenowska-Peschke, 2012)**

Another instance for the control phase shown in Figure 4 for the design of Hangzhou Tennis Center where a set of points were determined in a way to control generating the envelope.

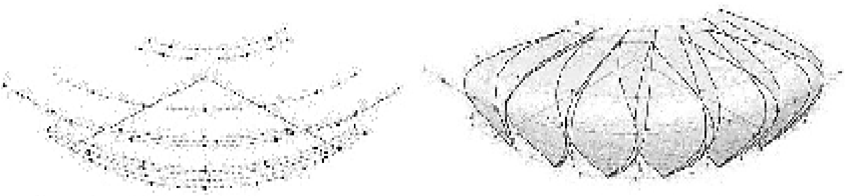


Figure 4: On the left the constrained points, on the right the control surfaces to generate the design variations of Hangzhou Tennis Center (Miller, 2011b)

2.2. GENERATION

Design is a process of search; for problems and solutions. Generation is the process of developing and synthesizing the solutions or ideas discovered from the problem analysis stage. Design exploration is about the generation of multiple options or alternatives (Hudson, 2010) as shown in figure 5. Parametric design as a computationally based design focuses on form finding at the conceptual design phase. Through programming, designers can develop computational environments that generate shapes based on pre-specified rules or other principles. Therefore, it facilities the rapid exploration of several design alternatives that respond to different design factors in less time, instead of drafting each design solution one by one. The number of the generated alternatives replies on how many parameters can be manipulated.

Figure 5: Generating different design alternatives for the British museum roof by Norman Foster (Burry and Burry, 2012)

Visually oriented computational tools are based on descriptive geometry or other mathematical means of defining lines, curves and surfaces. Parametric design facilitate the utilization of other methods to generate complex geometries that responds to several parameters such as repetitive algorithms, cellular automata, parametric definitions, "shape grammar" formulations, force density method and relaxation techniques. Some designers incorporate time into form definition, in which the geometry changes in time based on some prescribed principles or external forces. While others seek to dissolve the usual barrier between virtual and physical worlds. For instance, the design of robotic walls, where the design concept is influenced by the availability of the tools required to make its production possible (Yusuf, 2012).

2.3. Evaluation

The generated solutions are compared with the goals, constraints and opportunities developed during generation. All questions concerning the created design solutions are assessed during the evaluation process. If the design solutions meet the stated goals and can be modified, then it is successful otherwise the goals are redefined and solutions recreated as shown in Figure 7. The criteria on which the design is evaluated vary from project to project but can be considered in four main areas, structure, construction, aesthetics and environment (Hudson, 2010) as shown in figure 6.

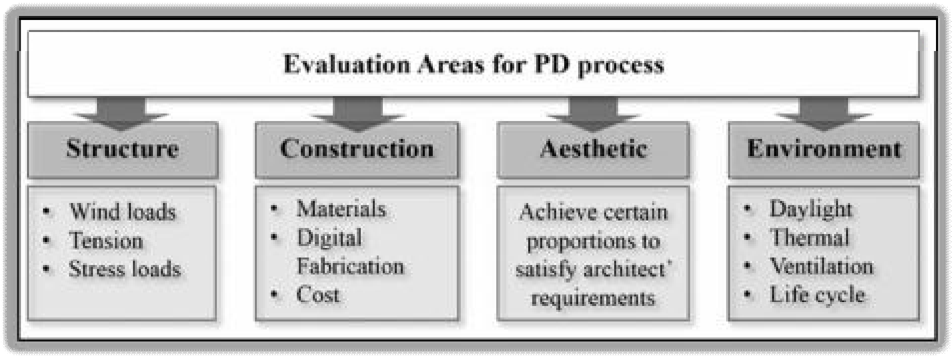


Figure 6: Chart to illustrate evaluation areas that can be integrated in PD process separately or by combing two or more of them, by the researcher after (Hu, 2014, Hudson, 2010, Turrin et al., 2011)

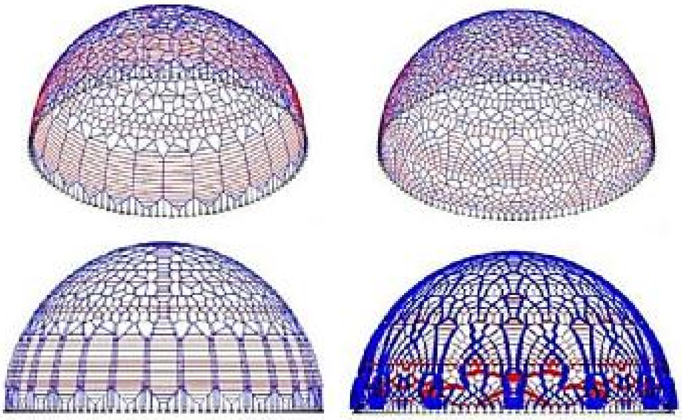


Figure 7: Generation and Evaluation of the Radio Dome structure Design (Turrin et al., 2012)

Descriptions of testing procedures that examines various criteria requires collaboration various specialist to define the evaluation strategy which might need to integrate different analysis programs within the computational environment created for this design. This collaboration aims to ensure smooth transitions between digital expression of design ideas and their analytical evaluations. Programs that enable this rigorous activity of development and evaluation include, Micro Station, Revit, CATIA, Pro/ENGINEER, Kangaroo Physics, SolidWorks and others (Hudson, 2008, Schodek et al., 2005, Yusuf, 2012).

For instance, Environmental comfort for the Elephant House was used as design selection criteria for the glazed roofs. The analysis, undertaken by external consultants, determined adequate shading levels for elephant based on the percentage of solar shading required, The finished pattern was finally output by the computer program (Peters, 2008) as shown in figure 8.

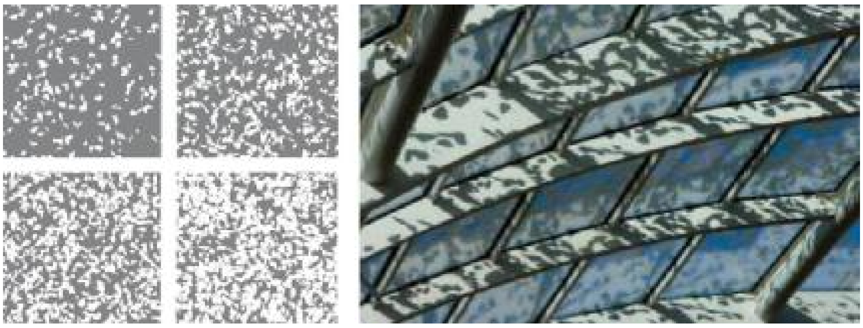


Figure 8: Four varying percentages of frit pattern on the left, the leaves pattern on the glass of the elephant house (Peters 2008)

Evaluation normally occurs in the design development stage and requires more time and effort. However, parametric design allows generating different design solutions while evaluating each solution at the same time to support designers with an immediate feedback in the conceptual phase.

2.4. Optimization

Optimization in design is to find the configuration that best matches the desired design goals. Solution finding through computational optimization is a new form of "Self- Formation Process" (Otto and Rasch, 1996).

- Optimization Criteria:

It is a selection criteria which is identified to search for the optimal configuration based on technical or aesthetic requirements. Usually, it is identified through numerical values and mathematical relations. For instance, optimization criteria was chosen in collaboration with civil engineers using a custom-developed application that has been developed within Arup for optimization to search for the best Stadium roof based on structural performance (Dominik et al., 2007) as shown in figure 9.

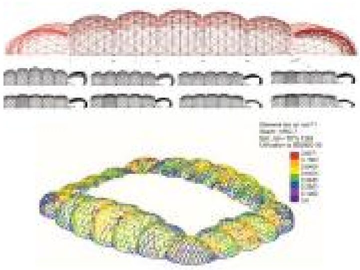


Figure 9: Generating Several Stadium roof configurations to be optimized by evaluating the stadium roof stress performance evaluation as in the bottom (Dominik et al., 2007)

- Optimization Types:

There are two types; **Single-Objective Optimization** is incorporated when there is only single objective to be targeted, to be maximized or minimized. **Multi-objective Optimization** is incorporated when more than one objective to be targeted, for instance to maximize a certain value and minimize another value at the same time.

- Optimization Methods:

There are several optimization methods as shown in figure 10 which is utilized by programmers to search for the best solution for a certain problem, it is divided into three categories based on optimization concept: **Numerical methods, enumerative methods and guided random search**

techniques. Parametric design allows designers to integrate some of these techniques to automatically manipulate the parameters to generate several alternatives that will be evaluated and based on selection criteria, the best solution will be selected.

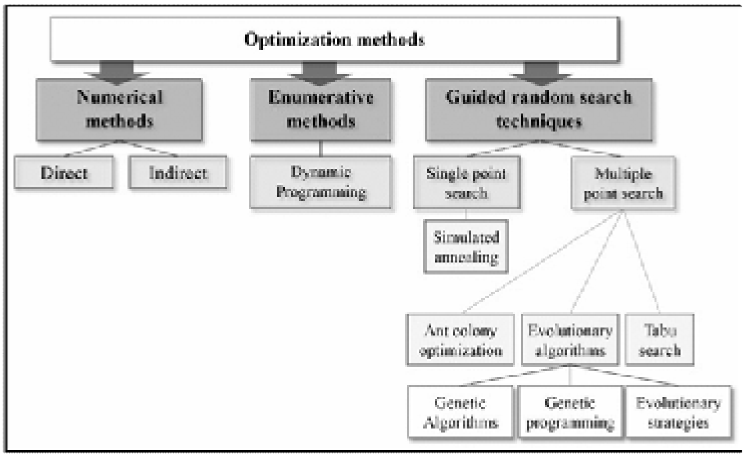


Figure 10: Chart to illustrate several optimization methods (Bandyopadhyay and Saha, 2013)

For instance, a Genetic algorithm driven search was utilized to explore different design configurations for a tower design (Kilian, 2006) as shown in figure 11.

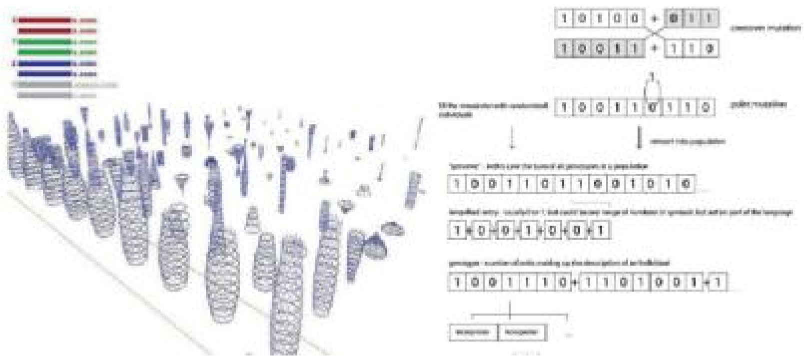


Figure 11: Genetic algorithm driven search for diagrid towers (Kilian, 2006)

Incorporating such methods in the parametric systems can be done by scripting the optimization algorithms to search based on specific function. There are some tools that was developed for designers with no good knowledge of programming techniques to integrate optimization methods that relies on GAs, such as Galapagos plugin, Goat plugin and Octopus plugin for Grasshopper. In Michigan University, ParaGen GA tool was developed as well to facilitate the exploitation of GAs to search different forms based on a certain performance (Turrin et al., 2011).

3. Application

- **SolSt Roof**

SolSt is solar energy transmission which is a free form roof covering an area approximately 50m x50m located in Milan, Italy.	
Designer	Michela Turrin, Peter von Buelow, Axel Kilian, Rudi Stouffs.
Design problem	Summer and winter conditions lead to evidently conflicting requirements, especially when focusing on the solar energy transmission and the airflow.
Design Goals	Design free form roof for: • Enhancing thermal comfort in summer and winter • Optimizing daylight • Optimizing the structure

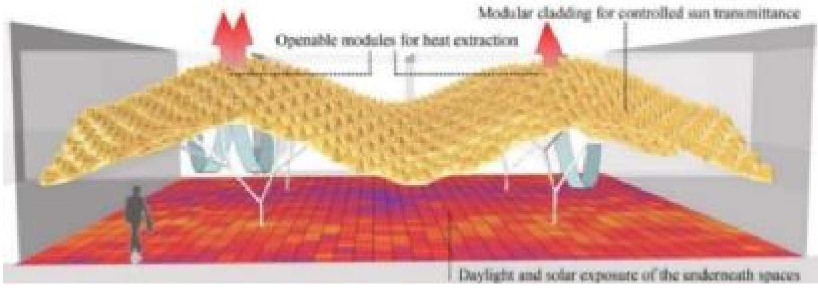


Figure 12: Solst Roof by Michela Turrin, Peter von Buelow, Axel Kilian, Rudi Stouffs.

Parametric Software	**ParaGen** to use GAs for the exploration of form based on performance criteria. **GC Generative Components** to parametrically generate tessellations.
BPS Tool	**STAAD Pro.** for structure analysis **Ecotect for daylight and ventilation**
Computational technique	Scripting, using mathematical functions and Genetic algorithms
Guiding performance	Structure performance, daylight through daylight Factor metric and thermal performance through the incident solar radiation.
Parameters	Grid points, the density of the tessellation, and the local inclinations of the cladding panels, openings angle, picks height

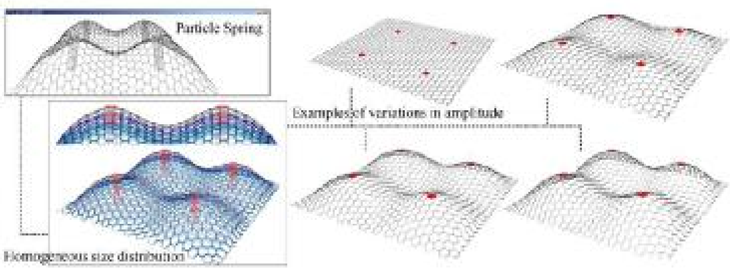


Figure 13: Variations generated by varying the heights of peaks

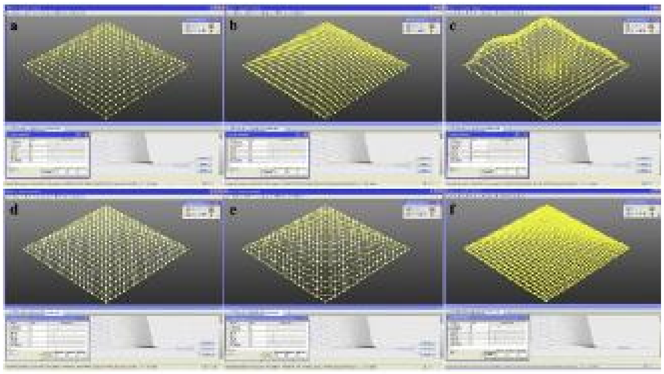


Figure 14: Varying the tessallation overall shape for SolSt roof.

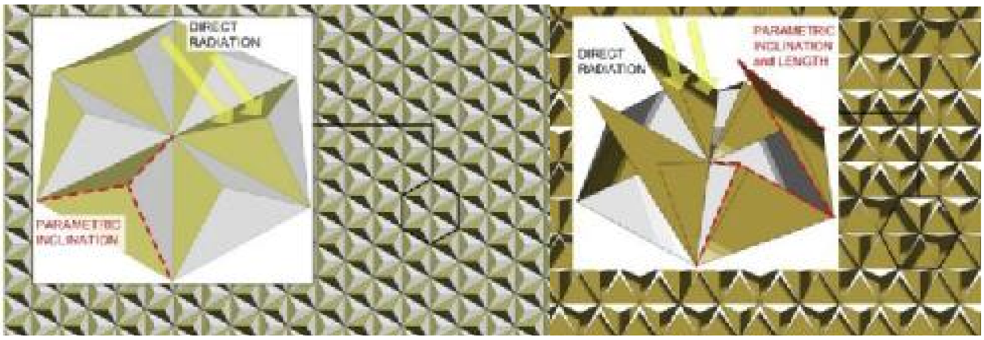


Figure 15: Opening parametrization for the cladding openings for SolSt roof.

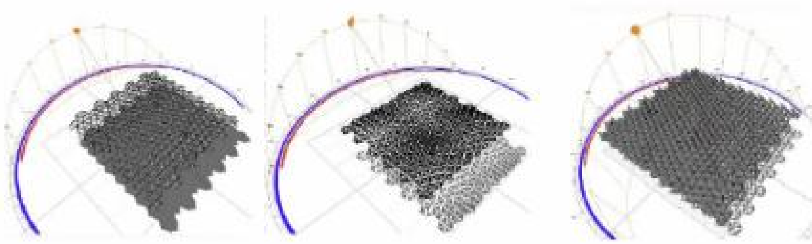


Figure 16: Evaluating daylight factor by Ecotect for SolSt.

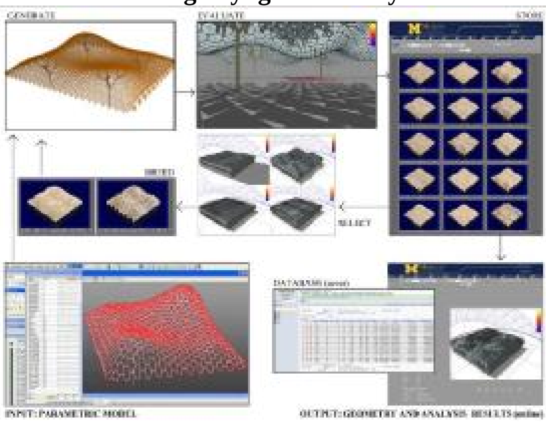


Figure 17: The parametric process for SolSt.

Parametric alternatives were explored by varying the parameters values. Several iterations were run for summer conditions and, for comparison, through the year, to get convergence of the design solutions by minimizing the solar incident radiation and by maximizing the daylight factor underneath the roof. Within a single-objective optimization process, the fitness function targets the ratio between the two.

4. CONCLUSION

Using parametric design in early design phase to solve complex design problems influenced the architectural design process by exploiting the capabilities of computation and the evolution of CAD tools. This requires a new way of thinking of the design problems and goals. Therefore, this paper discussed the parametric design process which is extracted from several studies. Parametric design process consists of four connected phases; Parametrization, Generation, Evaluation and Optimization.

Parametric design approach can be considered the most accurate tool to design based on a certain performance such as daylight, ventilation, structure, acoustic, etc. which is known as performance based design, as it facilities the process of enhancing performance in buildings and generating forms by integrating performance evaluation of a certain design requirement with optimization techniques to choose near optimum solutions in early design phases.

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