Information Processing and Assessment for Improved Computational Energy Modelling

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Abstract

This study explores how designer interacts with the computational model. This research intends to demystify how "design knowledge" is obtained, used and processed in the age of computation. The paper shows how the computational modelling tools associated with performance-based parametric design help support design decisions during the initial design phases. Building Energy Performance (BEP) is chosen as the main context to develop a set of criteria for the iterative development, testing, evaluation, and validation of a prototype model. Therefore, as a practical work, the research explores a series of new energy simulation modelling techniques based on parametric design and multi optimization-based design. Specifically, it aims to explore, develop, and test new approaches in parametric modelling that can support energy simulation, using multi optimization, where designers can easily state the design parameters and use them in energy-performance-based design. The exploratory research approach is the main theme of this research. However, during the development of the research it was found that there is a need to blend this research design with the descriptive research approach. One of the key contributions of this study will be the development of a more direct link and useful methods for the translation of information into data inputs to support computational thinking and modelling processes.

الخلاصة: يدرس هذا البحث كيفية تفاعل المصمم مع النموذج الحسابي. حيث تهدف هذا الدراسة إلى إزالة الغموض عن كيفية الحصول على "معرفة التصميم" "design knowledge"واستخدامها ومعالجتها في عصر الحاسب الرقمي. توضح الدراسة كيف تساعد أدوات النمذجة الحسابية Computational Modelling Tools المرتبطة بالتصميم البارامتري Parametric Design القائم على الأداء في دعم قرارات التصميم أثناء مراحل التصميم الأولية. تم اختيار أداء طاقة المبنى (BEP) باعتباره السياق الرئيسي لتطوير مجموعة من المعايير للتطوير التكراري والاختبار والتقييم والتحقق من عينة النموذج الأولي. لذلك ، كجانب عملي ، يستكشف البحث سلسلة من تقنيات نمذجة محاكاة الطاقة الجديدة بناءً على تصميم حدودي وتصميم قائم على أداء الاقة. على وجه التحديد ، تهدف إلى استكشاف وتطوير واختبار مناهج جديدة في النمذجة البارامترية التي يمكن أن تدعم محاكاة الطاقة ، باستخدام التحسين المتعدد ، حيث يمكن للمصممين بسهولة تحديد معلمات التصميم واستخدامها في التصميم القائم على أداء الطاقة. ان نهج البحث الرئيسي هو الاستكشافي. ومع ذلك، خلال تطوير البحث أن تبين ان هناك حاجة لمزج تصميم البحث هذا مع نهج البحث الوصفي. تتمثل إحدى المساهمات الرئيسية لهذه الدراسة في تطوير رابط مباشر أكثر وأساليب مفيدة لترجمة المعلومات إلى مدخلات بيانات لدعم التفكير الحسابي Computational Thinking وعمليات النمذجة.

1. INTRODUCTION

"I've seen many low-carbon designs, but hardly any low-carbon buildings"

Andy Sheppard, Arup, 2009

Architects regularly construct their models based on data and assumptions– either individually or collectively constructed through interpretation as a result of an internal thinking process, mental model– which are then translated into a computational model, Figure 1.
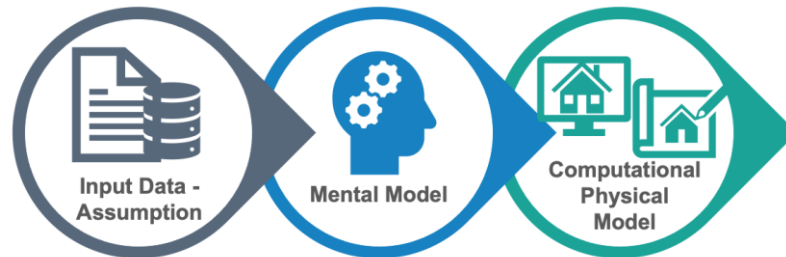
Figure 1 Input processing and outputs, [1]

Various sophisticated tools allow easy access to new ways of, evaluating, analysing, modelling, and assessing information. Similarly, new approaches and techniques for modelling geometric and non-geometric information and the ability to simulate alternative behavioural and performance scenarios are intended to enhance the design process overall and potentially, aid the creation of better design products and solutions. Yet, it is essential to understand how incomplete and ambiguous information is best utilized in the Conceptual Design Stage (CDS) to deliver more accurate outputs. If we consider tools as intermediary between inputs and outputs, then the outputs will be misleading if inputs are incorrect or if the tools do not serve the right purpose. If only one of the inputs is entered incorrectly or based on wrong assumptions the simulation output will not yield reliable results [1,2].

In the context of this research, we have observed the following as problematic key areas:

1. The process of translating/linking/maintaining information into the computational model at the right stage in the design process.
2. The interaction between the mental and the computational models.
3. The inputs that are used in different design stages, as design progresses.

Designers usually use ambiguous (fuzzy) inputs, especially during CDS, where many parameters have not yet been assigned [3]. Most designers refer to "default assumptions (or standards)" for the initial building energy performance (BEP) modelling, which eventually lead to uncertain outputs [4]. At the later stages of design, energy experts usually calculate the BEP based on more accurate, contextual information specific to the building in question. These detailed models are usually compared with early design/simulation models, which do not provide reliable progress as the comparison is between two different energy models with two completely different input sets.

Consequently, this research explores how architects process, utilize, and assess information before translating it into a computational model. This study intends to demystify how "design knowledge" is obtained, used, and processed in the age of computation. We conduct this investigation through "energy performance modelling" whereby we create the crucial link between "information" and "modelling" as the two components of computational processing of design knowledge.

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2. COMPUTATIONAL MODELING BASED ON DESIGN THINKING TO ENHANCE BUILDING PERFORMANCE

2.1. Design Knowledge and Modelling Tools

Design thinking is closely associated with the information at hand, previous experience [5,6], skills, and knowledge background [7,8] of the designer - whether the knowledge at hand is explicit and/or implicit [9]. It is widely accepted that the architectural design, especially in the CDS, has cyclic procedures of processing and transforming of design knowledge in order to create design solutions based on the problem definition, limitations, and requirements [10].

Just using tools accurately, technically, is obviously not sufficient, as the modeler would also need to have the knowledge, skills, and ability to translate information into data inputs correctly [11]. Also, the relationship between the objectives of design and simulation parameters might be too ambiguous to be understood, particularly when there are many dependent variables to be studied, correlated, and due to the non-linear nature of the problems at hand. Consequently, best design solution is not guaranteed [12].

It is accepted that many important decisions taken during CDS have huge impacts on the final building performance, even if there is not enough certainty and validity of the information used at this stage [13,14]. Additionally, to simulate building performance, architects need to create a model that is based on both geometrical and non-geometrical information [15]. Although Building Performance Simulation (BPS) tools are essential parts of this process, current tools are not designed to work with fuzzy information. Designers usually use the same tools in different design stages to simulate the BEP, although the type and nature of the information used and available at different stages vary considerably [16], Figure 2. Similarly, existing energy simulation tools do not support comprehensive parametric relations between building parts [17] – usually set by using other design/modelling environments. Therefore, one of the key objectives of our research is to explore the features of a new generation of modelling/simulation tools, which could aid the designers to process fuzzy/uncertain/imprecise information and at the same time support comprehensive parametric relations to be defined between different parts of the design.
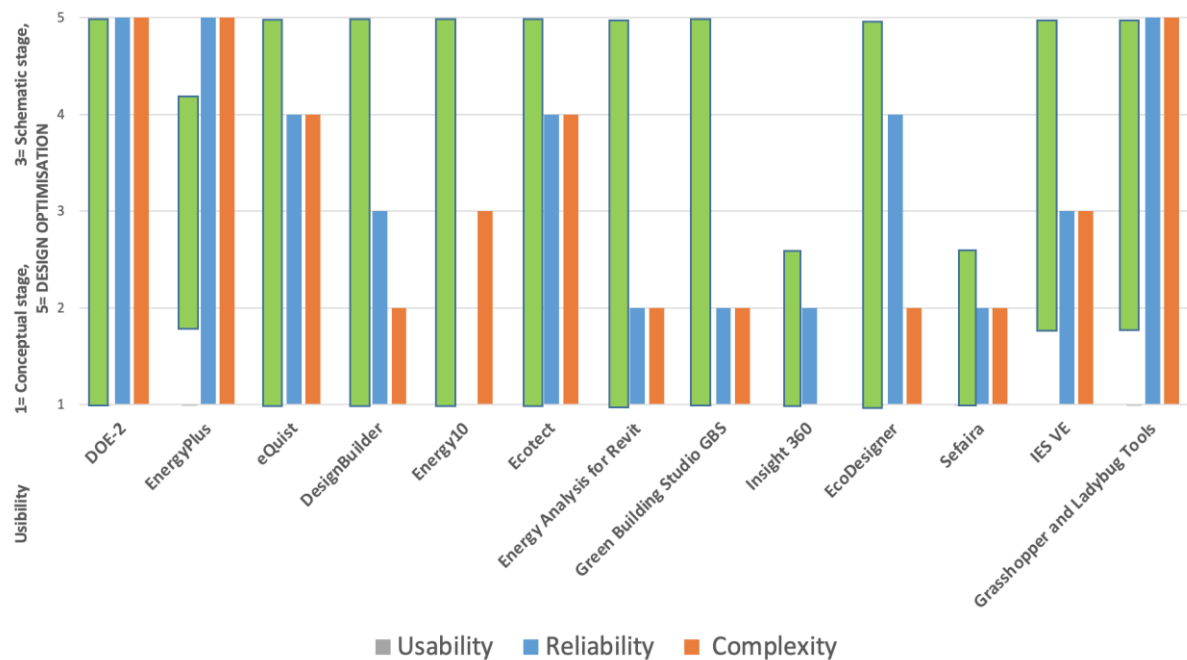

Figure. 2 Building Energy tools comparison, adapted from [16,18]

2.2. BEP Computational Modelling in Conceptual Design Stage

Many researchers, such as Asl et al. 2015; Basbagill et al. 2013; Ding 2008; Wang, Zmeureanu, and Rivard 2005; Kim, Asl, and Yan 2015, have demonstrated that design decisions, which are made early during the conceptual stage, have high impact on the BEP [19, 20, 21, 22, 23]. Moreover, BEP assessment processes are complicated multi-criteria problems and design practitioners commonly do not have sufficient knowledge to deal with them [1, 15]. Similarly, Asl, Zarrinmehr, and Yan (2013) observed that most traditional BEP analysis processes were *"useless and should be enhanced"[24]*. One of the problems associated with the inefficiency of these modeling tools/platforms is that there is no opportunity to generate and investigate a variety of design alternatives/scenarios, which could eventually lead to better performing buildings.

Bazjanac (2008) indicates that, frequently, simulation and analysis are launched after crucial design decisions have already been made, and thus it is inflexible to reduce the impact of these decisions on BEP, which might affect the future building performance [1]. Correspondingly, there is significant evidence suggesting that buildings are often not performing as predicted [4,26]. Carbon Trust, which is a non-profits organization, helps companies reduce their carbon emissions and become more sustainable, states there is a considerable gap between predicted and actual energy consumption, Energy Performance Gap (EPG), of our buildings, Figure 3.
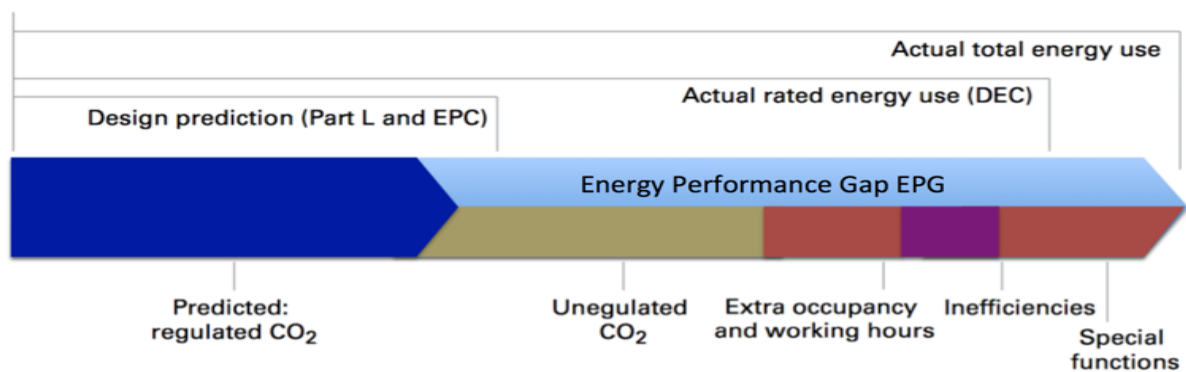

Figure . 3 Energy performance gap (EPG) [27].

3. ENERGY PERFORMANCE GAP EPG IN THE DIGITAL AGE

Rapid technological development has led to further improvements in the tools we use that effectively enhance the design processes and products. Some of these tools offer new possibilities to evaluate building accurately [28]. However, one of the most important questions to ask today is: *why is EPG still so high, despite highly advanced developments in the tools that we use?*

According to Demanuele, Tweddell, and Davies (2010); Menezes et al. (2012); Zero Carbon Hub (2014), the causes can be explained according to the nature of the various stages of a project: design, construction, and post-occupancy phases [3,4,28].

At the design stages, model simplification, wrong/inaccurate inputs, insufficient digital tools, unexamined/missed factors, and lack in communication (designers/owners/occupants) are the main reasons. At the construction phase, wrong choice of building materials and systems/components, faulty fabrication, and inefficient construction techniques are identified among others. During the post-occupancy, occupants' behaviour, operational management, and building use are among the most important causes. According to our research hypothesis, the discord and lack of continuity between different design stages incurred by the use of different and inadequate modelling tools and techniques are among the causes of the EPG. The models and tools do not communicate to each other and disrupt the thinking process. As a response to this problem, in this study, we aim to offer a new modelling

approach which can enhance the designers' interaction with the models, and which can establish continuity between different stages of the design and development cycles.

4. DECISION-SUPPORT TOOLS BASED ON PARAMETRIC MODELLING

Existing energy simulation tools do not support comprehensive parametric relations between building objects [17]. Whilst parametric modelling tools have succeeded in creating associative approaches for defining and studying design constraints, they have not been developed to integrate performance feedback into the design process [27]. Tools that can support the designers to process uncertain information whilst allowing the modelling of comprehensive parametric relations are of necessity.

Tools also that aid the decision-making process can be developed, allowing designers to assess the performance of design alternatives swiftly and iteratively by connecting analysis applications to parametric design software, instantaneously decreasing the complexity of simulation inputs to suit early design processes [27,29]. Specifically, added programming possibilities could allow the continuous generation and evaluation of parametric variations in order to select optimal design solutions [30]

5. RESEARCH METHODOLOGY AND THE MAIN RESEARCH SCOPE

EPG is generally attributed to the lack of ability and efficiency of existing modelling techniques in representing the real information of building energy consumption. Despite improvements in current design/simulation tools, the impact of various factors on the BEP is not modelled appropriately.

The proposed approach aims to generate a new modelling technique/approach, which enhances the designer interaction with the model and creates more visible and traceable continuity between the thinking, assumptions and decisions taken in all design stages. This approach might help to understand the building behaviour more accurately, because we believe that such continuity will provide information, which could not be obtained via the traditional modelling process. This research focuses specifically on the conceptual design stage as it is considered the most crucial phase for the building behaviour.

5.1. Research design

The main theme research design is exploratory, however, based on the various questions emerged, and hypotheses that were proposed to continue the direction of existing research suggested that there is a need for mixing this research design with descriptive research approach. Exploratory research is one which aims at providing insights into and an understanding of the problem of the use of technology to support the design decision-making of designers and students during conceptual stages.

From another point of view, descriptive research aims to describe the importance of current technologies (e.g. parametric and energy simulation tools) to obtain quick and accurate feedback during the early design stage, to support the design knowledge and design decision making of architectural students.

6. EXPERIMENTAL WORK

The aim of the experimental work is to explore a series of new energy simulation modelling techniques based on parametric design. Specifically, the experimental work aims to explore, develop, and test new approaches in parametric modelling that can support energy simulation, using design-optimization process, where architects can easily state the design parameters and use them in optimization-based design. Then the optimization tool provides the designers with many design alternatives based on the specified parameters. Where the architects can view the ramifications of their design changes on the BEP and track changes in their design. The proposed technique is intended to support both modelling and synchronous adjustment of the performance criteria. This approach aims to generate an energy

model where all input information, data history through the design and development stages, can be tracked and compared together with the assumptions in each respective stage. Also, the designers can study and evaluate multi design alternatives.

6.1. Experimental Work Description

The experimental work uses the Rhino/Grasshopper 3D, as a parametric tool, and the Ladybug, a building energy simulation plugin for Grasshopper 3D, and Galapagos tool as the optimization tool. For the optimization-based design, the parametric inputs work as genomes and the building energy performance, solar radiation, represent the fitness in this process. In the next section, a case study is presented to explain the impact of using a multi-optimization-based design by examining 50 auto-generated design alternatives.

6.2. Case Study

This case study is based on a parallelogram of blocks distributed on a curved line path of a length of 90 meters. There were three parameters that could be changed to obtain the best design in terms of thermal gain among the 50 proposals. The first criterion was the width of the parallelogram, which was between 3 to 10 meters. The second criterion was the inclination in the facade, as it was 5 meters away in both directions. The third parameter was the degree of curvature represented by a point located perpendicular to the curved path and with -10 and 5 in both directions, as shown in Table 1.

7. RESULTS AND DISCUSSION

As 1500 design alternatives were produced using these parameters by employing the design - optimization tool, and they were distributed based on the calculation of the thermal gain result from the least gain to the most. Table 1 shows 3 proposals inputs, including Block width, Façade inclination and Curve point, and outputs, Total thermal gain in Kw/Yr. Option 1, Figure 4, represents the best of them being the least in terms of total thermal gain, which is 1510286 Kw/Yr, the Genomes used for the Block width is 3, the Façade inclination is 0 and the Curve point is -5. On the other hand, Option 3, Figure 6, is the worst alternative among 1500 generated alternatives regarding receiving the solar radiation, 1683192 Kw/Yr, in total. The inputs used for the Block width is 9, the Façade inclination is -5 and the Curve point is -8. Additionally, the total thermal gain of Option 2, Figure 5, works as the middle result from the total 1500 design options. From Table 1, the Genomes of Option 1, the Block width (3) and Façade inclination (0) are the lowest value, and the curve point location is on the average value. On the contrary, the Genomes of Option 1, the Block width (9) and Façade inclination (-5) are the lowest value, and the curve point location is on the highest value.

From these findings, it can be said that a more fragmented shape performs better than one block form in terms of reducing the thermal gain, this might be due to the fragmented shape casts more shadows on its surfaces. Similarly, the vertical shapes receive less solar radiation. Though, to generalise these findings we should consider the form's other specifications and the geometry orientation.

Table 1 Case study thermal gain and parameters

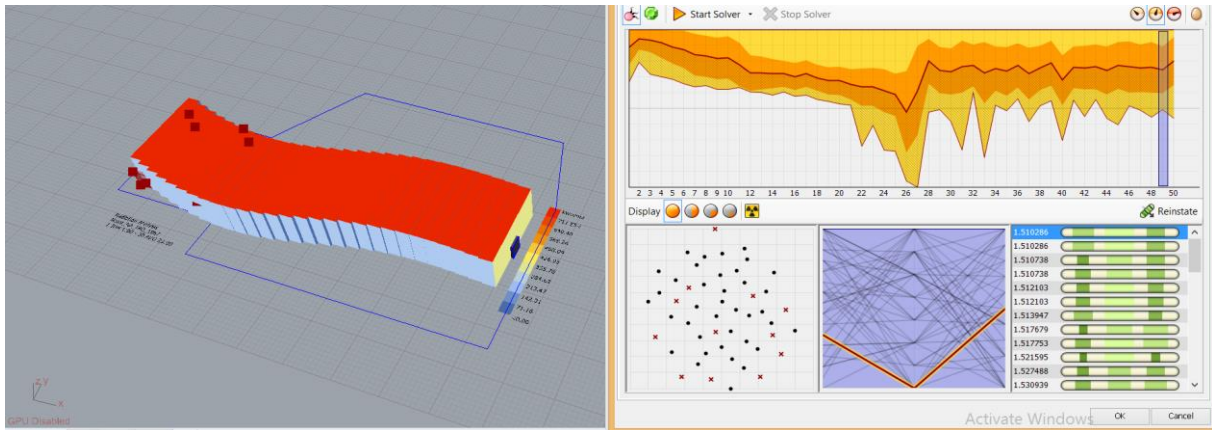| Design Alternatives (Options)	Genomes			Fitness
	Block width 3to10m	Façade inclination -5to5m	Curve point -10<5	Total thermal gain Kw/Yr
Option 1, Figure. 4	3	0	-5	**1510286**
Option 2, Figure. 5	9	-1	-3	1612746
Option 3, Figure. 6	9	-5	-8	1683192

Figure . 4 Design Alternative (Option 1), total solar radiation = 1510286 Kw/Year
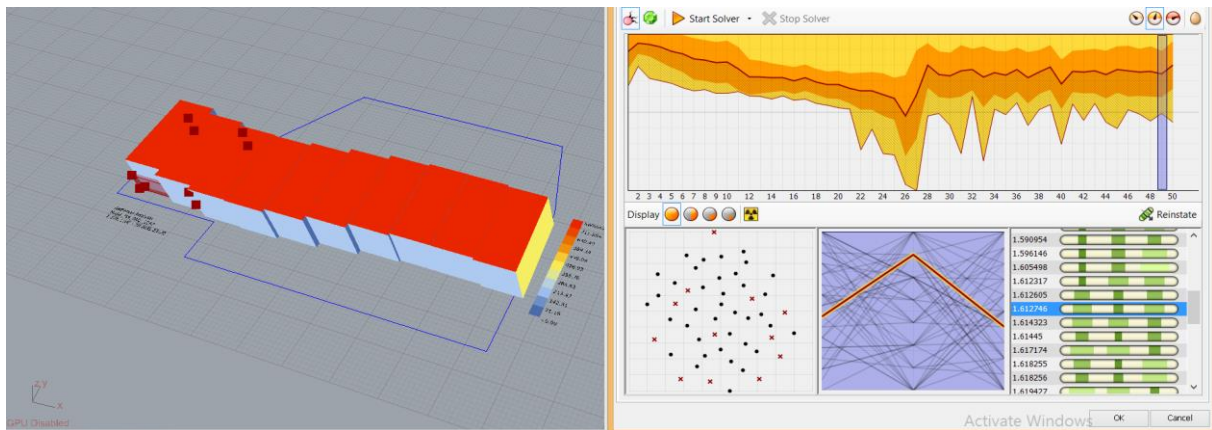

Figure . 5 Design Alternative (Option 1), total solar radiation = 1612746 Kw/Year
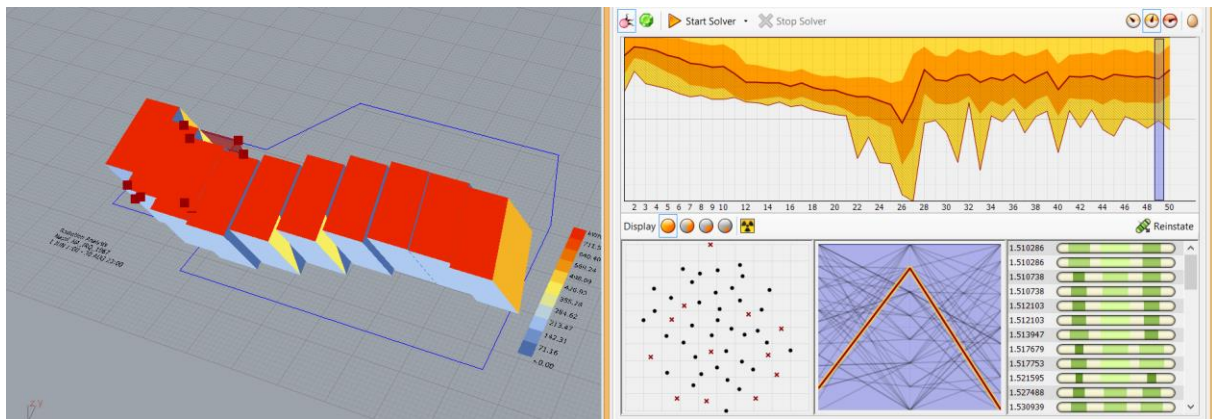

Figure . 6 Design Alternative (Option 1), total solar radiation = 1683192 Kw/Year

8. Conclusion

In conclusion, this paper emphasizes the current problem of the disconnection between thinking, conceptualizing and information modelling during different design stages. The presented research aims to develop a new modelling technique which enhances designer's interaction with geometric and information models and thereby facilitates continuity between early and later design stages and decisions. BEP is chosen as the main context to develop the set of criteria for the iterative development, testing, evaluation, and validation of a prototype.

Whereas the most important finding in this research is that the use of design-optimization tools in parametric performance-based design allows the designers to analyse and evaluate multiple design alternatives that are difficult to calculate manually and thus choose the design closest to desire, avoiding the role of thump that is sometimes counter-productive. Consequently, the results show that, that a more fragmented geometry functions better than one solid shape regarding reducing the solar impact, this might be due to the fragmented geometries cast more shadows on the surfaces exposed to solar radiation. Likewise, the shapes without any inclination obtain the lowest thermal gain. Although, the other factors of the form and its orientation must be considered to conclude these hypotheses.

Thus, future research work must take into consideration these other geometry factors. Additionally, these research processes and outcomes could be enhanced by using multi-Optimisation based design study, and the use of Building Informational Modelling BIM to support the data collection and management. Therefore, studies that cover these two topics are highly recommended.

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