Performance-based design

Report of an academic workshop with energy efficiency simulation tools

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This article presents the results of a Seminar / Workshop named "Energy Modelling: Preliminary Analysis of an Architecture Project", organised at the University of Minho's School of Architecture, Art and Design, located in Guimarães. The Seminar / Workshop aimed to teach students on the use of simulation tools that evaluate the energy performance of building's architectural design. It demonstrates the importance of simulation software as a tool to design energy-efficient architecture in the early stages of a project. The Seminar / Workshop introduced students to fundamental notions of simulation related to thermal and natural lighting comfort, like modelling methods, interpreting the obtained results and procedures for improving the results. Despite presenting different simulation software during the workshop, the exercises proposed to the students focused on using Climate Studio because of its versatility and compatibility with different architectural modelling software. The software is relatively recent and can be adapted in different project phases. The students learned the benefits of using simulation software to obtain information for further improving an architectural project. The simulation helped students understand the passive design strategies that can improve thermal comfort in the building. Like making the best use of the landscape, the shape of the building and its position and not just by increased insulation in the envelope, well-oriented glazing, optimised thermal mass, controlled ventilation or shading. Therefore, the students learn that simulation tools allow for optimising the passive strategies to their limits in the design stage.

Keywords: *Multi-criteria Simulation, Functional Analysis, Economic Analysis, Parametric Design.*

INTRODUCTION

This article presents the results of a workshop that took place in an academic context, at the University of Minho School of Architecture, Art and Design. This workshop was developed within the framework of the "Innovation and Technology" Module, in the first semester of the fourth year of the Integrated Master in Architecture. The Module is developed under the Scientific Area of "Construction and Technology", being composed of three Curricular Units (CUs): "Studio 2B – Innovation and Technology", "Seminar 2B – Innovation and Technology " and "Compulsory 2B – Special Structures". The challenge to the students of this Module is to question the current knowledge of Architectural design, including the materials and construction systems and new ways of applying these in buildings, namely by the integration of computational design and simulation tools for the architectural and functional assessment of the design solutions in the academic year of

2021/2022. Environmental concerns are relevant aspects in this Module, as well as in other moments of the University of Minho's Architectural Curricula. (Mendonça, 2011; 2012)

STUDIO 2B

Studio 2B Innovation and Technology CU main goal was to stimulate the integration of digital tools in Architecture and Construction to promote a more sustainable built environment. The syllabus is the design of a high-rise building for a student dormitory that incorporate prefabricated and reversible building systems. The students should consider structural and constructive systems based on principles of repetition and variation, allowing to test design languages that are established from parametric relations between the parts and the whole, helping to define design solutions that respond to specific conditions of the program and the morphological and constructive principles of the project. This exercise is divided into three subsequent phases: Morphogenesis, Skeleton and Skin. The Preliminary Analysis of a design proposal makes part of the last phase, concerning the definition of the composition system and material of the façades, focusing on their role in the environmental control of the building. Similarly, to the statement of the previous phase, the definition of principles of repetition and variation, as well as the inclusion of prefabrication systems and reversible principles for the façade cladding system.

SEMINAR 2B

Seminar 2B CU aims to stimulate critical thinking and innovation on the relationship between materials, systems and construction. During the classes were initially presented and characterized the materials and conventional building systems and subsequently raised new possibilities. These new possibilities should enhance functional advantages with unexpected tectonic approaches. In phase 1 students performed a comparative analysis of case study buildings selected by them. Phase 2 is individual and consists of the design and functional optimization of the bedroom modules used in the Studio 2B project, with a special focus on the design of the respective exterior façade including vertical and horizontal section details. It includes a thermal, acoustic, environmental (embodied carbon), economic cost and natural lighting evaluation. For this analysis and, among other functional assessment tools, the Climate Studio software was used, with the support of a workshop developed together with the Studio 2B CU.

WORKSHOP ON ENERGY PERFORMANCE-BASED DESIGN

The workshop took place during Seminar 2B and Studio 2B classes between the 17th and 25th of May 2022, extending until the 7th of June 2022 to support the students with their work in both CUs.
Computational methods were introduced for the energy and functional modelling, by using CimateStudio, a Grasshopper plug-in. By associating solar radiation simulation models with the parametric model that defines the façade surfaces of the building, students were able to optimise the recommended solutions for the design of openings, shading, etc., according to the uses and solar exposure.

ENERGY PERFORMANCE SIMULATION SOFTWARE

Designing a building is a multidisciplinary process which unites different fields of expertise. In this process, the various areas involved try to bring the best of their worlds to create a coherent and functional project. That means not only considering architectural design but also structure, urban planning, lighting, thermal and acoustic comfort, among other issues.

Sometimes, the aesthetic aspect of architecture is overvalued compared to its functional behavior. The lack of balance between these two aspects makes architects think of these two aspects as dependent and sequential instead of them being simultaneous. As a result, it can lead to buildings that fall short in their technical aspects and are only aesthetically well developed.

Even if architects do not have a complete knowledge of the different fields mentioned above, they must have a basic understanding of the different expertise that is involved in building processes. This broad understanding of different fields ensures that technical aspects of energy performance get also considered during the preliminary design phases. However, if this is not the case, the developed projects need more interventions by specialists later. The use of digital models for thermal, lighting, energy consumption, and other functional behaviour evaluation of the project, are valuable tools to guarantee the comfort and efficiency of the buildings.

When talking about energy performance simulation models, we refer to different algorithms that simulate energy balances and heat transfers between spaces and surfaces. Using this type of quantitative and qualitative performance-based simulation model allows architects to understand the expected behaviour of the designed rooms and built environment quickly without having to build the element first to be analysed later. They also contribute to eliminate the classical distinction between architects and engineers and promote digital collaboration between the two by blurring the distinction between geometry and analysis and appearance and performance (Kolarevic, Malkawi 2005). This type of software enables quick analysis of an element using a computer-generated 3D model to modify the element and improve the results quickly, as showed in the Figure 1.

The first step is always creating a computer-generated 3D model and inserting the building data in the software like the composition of the different building elements, warm water schedules, ventilation rate and among others. The next step is to upload an EPW file in the software, which gives the climate data of the location where the project is situated. The simulation uses the climate data from the EPW file to simulate the building's behaviour in that particular location. After the simulation, the given results are used for analysing and drawing conclusions to make a set of design decisions. The architects and the engineers can thus work together and iteratively to develop the optimal design solutions.

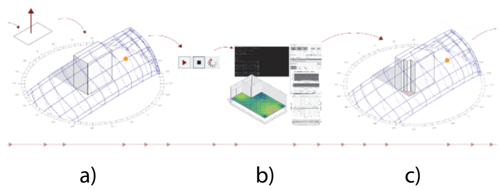


Figure 1
Scheme representing the design and simulation process; (a) creation of a 3D computer model and insertion of the building data; (b) Running the simulation considering an EPW file; (c) analyses of the results conclude, improve the model and repeat

The timeline presented in the Figure 2 represents the evolution of simulation software over the years.

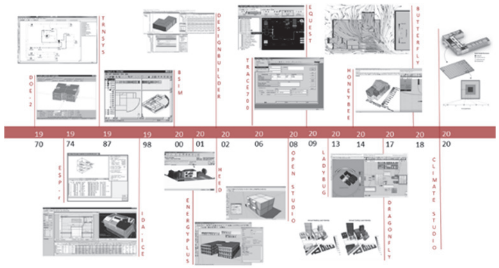


Figure 2
Timeline representing the evolution of comfort simulation software

Simulation software has come a long way since the first simulation software was introduced. The advances in technology and the different scientific research in optimizing the building design have led to simulation software like the Climate Studio. Current simulation software are based upon the research that was done using algorithms to determine optimum building shape, orientation, wall and roof constructions, window type, window area, foundation, infiltration rate, insulation thickness, and shading of residential –buildings (Kobeyev, Tokbolat, Durdyev, 2021).
As a result, simulation software like Climate Studio is now more intuitive and easier to use for all the different design stages. Unlike past software, Climate

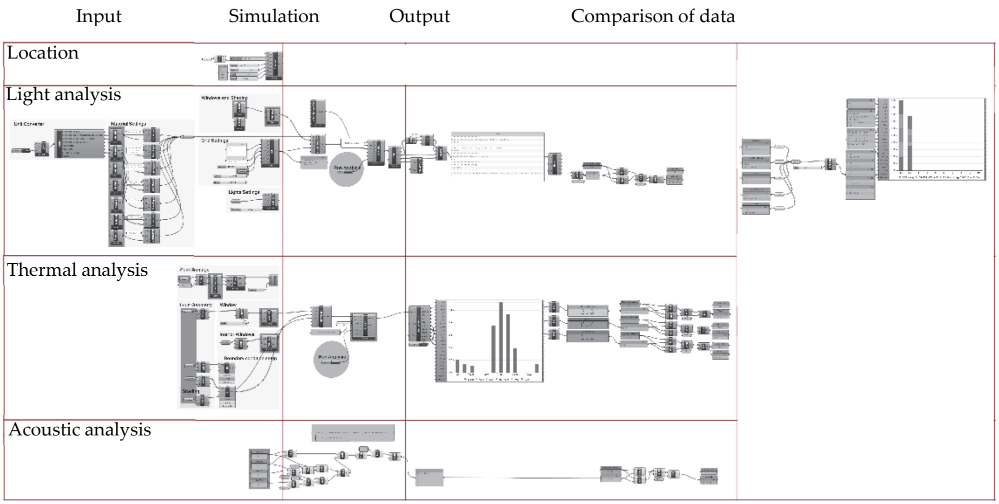


Figure 3
Grasshopper model used during the workshop

Studio can be used even in the conceptual design phase and the further stages of a project.

ENERGY PERFORMANCE-BASED DESIGN WORKSHOP RESULTS

To accomplish their energy performance-based design, during the workshop students were introduced to different simulation methods through video tutorials and oral presentations, with a special focus on Climate Studio to conduct a set of simulations related to the project proposal under development in Studio 2B. In addition, the students learned to do point-in-time Illuminance analysis, daylight autonomy analysis, annual glare analysis, thermal analysis, radiance rendering, and define shading elements like curtains or blinds with the support of Seminar 2B.

The Grasshopper model (Figure 3) is divided into four modules: input, simulation, output and data comparison. Being focused on five parameters of analysis: Daylight autonomy related to natural light analysis; Site Energy Use Intensity; Economic Cost related to thermal analysis; Embodied Carbon and Exterior Walls Insulation.

The students first learned to perform different analyses using Climate Studio in Rhino because of its intuitive and relatively easy-to-learn interface.

After, a Grasshopper model (Figure 3) was given to the students to introduce them to the use of Climate Studio in Grasshopper and demonstrate the benefits integrating it in a computational design workflow. In addition to offering a more diverse way to import and export data, it allowed the students to interactively compare their analysis data with a given reference solution. The reference solution was established using the results of a reference project created using the same project syllabus as given to the students (Figure 4). The project syllabus considers a residence to accommodate 400 students, composed by double rooms of approximately 40m2, support kitchens (minimum of 1 kitchen per 20 students), study areas and common social areas. The base project is a simple rectangular volume with a standard constructive detail used in Portugal. Exterior walls composed by: 1cm cement plaster; 8cm EPS; 20cm concrete blocks 1 cm cement plaster; 0.25cm paint / Interior Slab composed by: 0.75cm clay tile; 1cm cement plaster; 20cm reinforced concrete; 1cm cement plaster;

0.25cm paint / Interior wall composed by: 0.25cm paint; 1cm cement plaster; 9cm brick; 1cm cement plaster; 0.25cm paint.

The following simulation results are from the two selected student works, who used the given Grasshopper model and could analyse the referred parameters to compare the impact of various design decisions. When the workshop started, every student analysed their design proposal (1st option), improving it during the workshop and producing the following results.

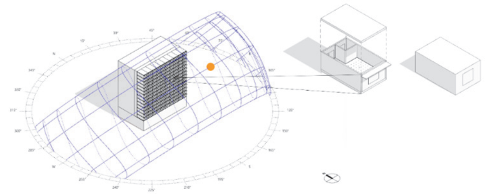
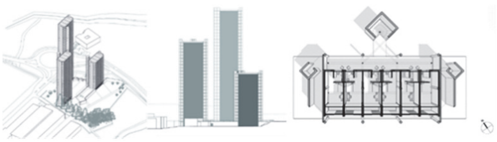


Figure 4
Reference Solution



a) b) c)

Figure 5
a) building axonometry; (b) building facade; (c) building standard plan

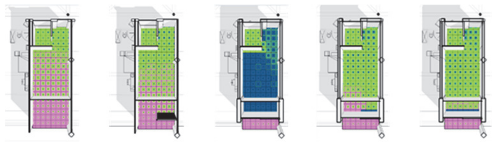
CASE STUDY 1

This case study had as an improvement reference the social housing project by Lacaton & Vassal in Bordeaux (2016), where they attached a winter garden to the existing facade. Similarly, in this case study, the winter garden becomes a new space that plays the role of thermal buffer and passive radiator, composed of two walls of French sliding glass windows separated by a 1.20m distance, sliding blinds with horizontal slats and an outdoor balcony, so, depending on the season and time of day, the slats can be oriented, letting the sun penetrate the apartment through the winter garden or closed to block the sunlight. Which means that the French windows can be opened or closed to cool or warm the student's room (Figure 5).

Ideally, during winter, the slats are oriented to let the sun enter the room, warming the winter garden, the ground, and then the CLT pavement. The winter garden heats up and transmits its heat to the student's room because of the easy thermal conductivity of the glass separating the winter garden and the room. In the mid-season, the slats are oriented so that the sun warms the winter garden and the room. If it is too hot, the inhabitants can open the winter garden to the outside. In summer, the balcony prevents the sun from entering the winter garden, and the windows can be left open to allow a pleasant draught of air in the apartment. If necessary, the slats of the blinds can be closed to obtain darkness in the room.

Useful daylight illuminance analyses.

Figure 6 illustrates that on the student's first try, there was a disturbing amount of light reaching the room's interior space from the south façade. Therefore, in the second option, the student added a shading element to the room's balcony to control the light entering the room, creating a semi-outdoor living space or a winter garden.



a) b) c) d) e)

Figure 6
(a) 1st option-open balcony; (b) 2nd option- open balcony with shading; (c) 3rd option- winter garden shading full closed; (d) 3rd option- winter garden with half shading opened; (e) 3rd option-winter garden with shading at 45º

The thermal and lighting results of the first and the second simulations were improved by making a winter garden where the amount of light entering the room can be controlled by using shading blades that are entirely closed, half-open or at different angles. In the following figures, it is possible to see the variety in lighting intensity along with the different room options.

Daylight autonomy analyses.

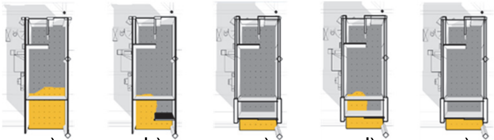
In figure 7, it is possible to verify that the daylight autonomy values in option three and its variations are lower than in the first two solutions. However, the values are still high, and the building is provided with sufficient daylight, even when the shading slats are semi-closed.

a) b) c) d) e)

Figure 7
(a) 1º option-open balcony; (b) 2nd option- open balcony with shading; (c) 3rd option- winter garden shading full closed; (d) 3º option- winter garden with half shading opened; (e) 3rd option-winter garden with shading at 45º

Sunlight Exposure analyses.

Regarding the sunlight exposure analysis, in the first option, direct light entered the room, heating the room and creating areas of glare that could be controlled when the student added shading to the second option. In the different variations of the third option, the direct light does not enter the room even when the shading blades are half-open (Figure 8 (e)).



a) b) c) d) e)

Figure 8
(a) 1º option-open balcony; (b) 2º option- open balcony with shading; (c) 3º option- winter garden shading full closed; (d) 3º option- winter garden with half shading opened; (e) 3º option-winter garden with shading at 45º

The student has also created the possibility to let the shade be half-open (Figure 8 (d)), allowing direct light to penetrate the winter garden area and even the room.

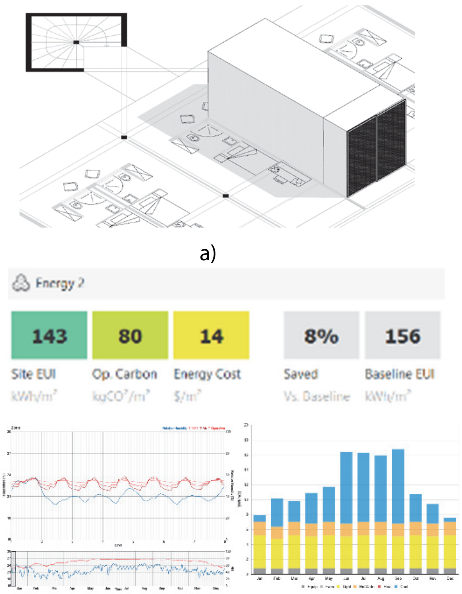
Thermal analyses.

Using the thermal analysis model, the student obtained results such as the relationship between the temperature and the humidity, the intensity of energy costs, the embodied carbon and others. (Figure 9) Which proved that "the outer layer or the tempered glass protects the building from external conditions and provides additional sound insulation from external noise, while the inner layer consisting of double glass provides additional thermal insulation of the outer shells to reduce the heat transfer in winter." (Design Builder, n.d.). This method saves 8% compared to a standard solution generated by Climate Studio in Rhino.

Grasshopper code global results.

Using the grasshopper code, the students could compare the different results and solutions to a reference solution. For example, figure 10 shows the results of the different solutions regarding case study 1, proving that despite the first solution having good results, the third solutions are better because the graph is not considering the percentage of space in the room that has disturbing light.

With the analysis and interpretation of the referred data, the student was able to improve the shape of his building to have good results and reduce the amount of intolerable light and disturbing glare in the room.



a)

b)

Figure 9
(a) thermal analysis model; (b) thermal analysis results

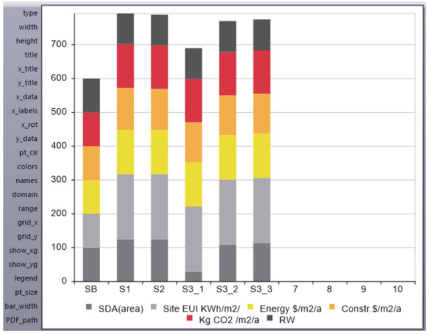
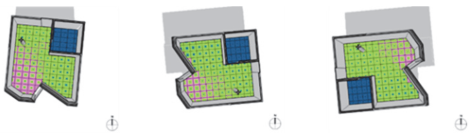


Figure 10
Comparison of the results of the several solutions regarding a reference solution

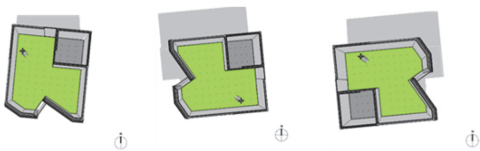
a) b) c)

Figure 11
(a) building axonometry; (b) building floor plans; (c) building section



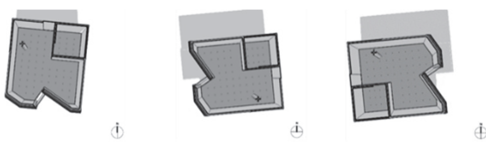
a) b) c)

Figure 12
(a) 1º option- façade facing south; (b) 2º option- façade facing west; (c) 3º option- façade facing east



a) b) c)

Figure 13
(a) 1º option- façade facing south; (b) 2º option- façade facing west; (c) 3º option- façade facing east



a) b) c)

Figure 14
(a) 1º option- façade facing south; (b) 2º option- façade facing west; (c) 3º option- façade facing east

CASE STUDY 2

This building is composed of two separate blocks, which through the rotation and translation of the floors, end up uniting on the upper levels into a single block. The structure comprises metallic pillars with a cross shape and collaborative slabs. The facade of the building is wholly clouded up in aluminium. (Figure 11)

Useful daylight illuminance analyses.

In this case, the student decided to explore the possibility of arranging the rooms along with the twisted tower floor plans. (Figure 12) Therefore, the first option (a) is located on the 33º level and the second and third options are on the fourth level but in two different towers. In the first option, there is an intense light near the window because the room faces south. On the other solutions, although the rooms do not face south, they have a good amount of light entering the rooms with some intense lightning. If necessary, "An adjustable shading device (blinds) can be installed in the air channel to protect from the sun and control solar radiation." (Campagna, Carlucci, Russo, 2021)

Daylight autonomy analyses.

Figure 13 shows that the Daylight Autonomy is secured throughout the whole room except in the bathroom, which is completely closed and has no light.

Sunlight exposure analyses.

Although the spaces have high daylight autonomy values and even some intense lighting near the window, the building cannot overheat because none of the solutions (Figure 14) have direct sunlight exposure. That allows the building not to overheat due to the student's facade design and chosen shape.

Thermal analysis.

The solution presents an improvement concerning the reference solution generated by the Climate

studio in Rhino of 39%. However, it presents a high value relative to the Embodied Carbon.
The data presented in figure 15 shows that when the shape of the building is designed by taking into account its luminous and energy efficiency, the final results are better. In this case study, the three room's facade is not entirely facing south like it is recommendable, but the fact of still having better analyses results shows that other solutions, despite the conventional one, are also worthwhile considering.

Grasshopper code global results.

As Figure 16 shows, only solution two is a little below the expected levels. The remaining solutions present similar and more significant results than the reference solution. Although none of the rooms faces south, the irregular shape of the facade with angular windows gives good average analysis results even if some rooms are a little below the reference solution results.

DISCUSSION

"The loss of thermal energy through the external enclosing structures of buildings is one of the main components in the structure of the costs of thermal energy spent on heating and cooling and accounts for 30-50% of all heat energy loss." (Gao, Bai, Mao, 2014) Therefore, using analysis software from the first project phases allows to improve comfort and building design results.

During the workshop period, the students were assigned the same project statements. They first designed and analysed their first project ideas. Upon which they further improved their design to achieve better comfort using the simulation software.

Figure 17 compares the results of the different students and the applied solutions with the reference solution. In the first case study, a winter garden area protected by a movable shade was designed to control the amount of direct and indirect light entering the space and thermal transfers.

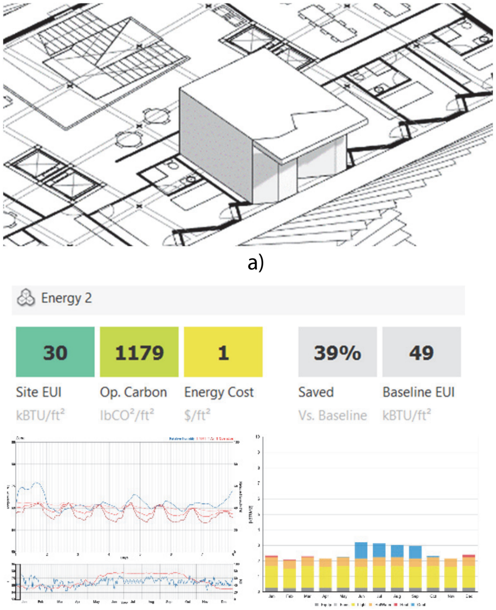


Figure 15
(a) thermal analysis model; (b) thermal analysis results.

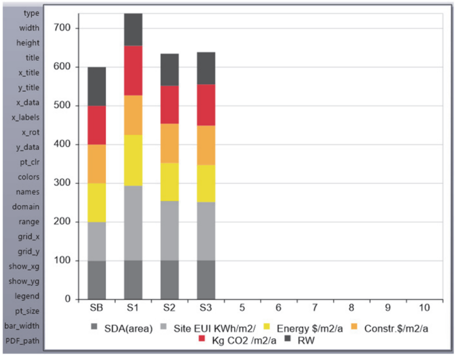


Figure 16
Comparison of the results of the several solutions regarding a reference solution

The use of this method allows the students to realise that the external shading can prevent the room from overheating but also heat the room when necessary. The winter garden functions as a thermal sweeper; this was the student's third solution. The results shown in Figure 17 are the average of the results where the shade is half-open, half-closed, with the shading blades half-open and fully closed (Figure 6,7,8 (c) (d) (e)).

The results show that the student improved his solution in all the parameters, such as Daylight autonomy, Site Energy Use Intensity, Economic Cost, Embodied Carbon and Exterior Walls Insulation.

In the second case study, the student tried to find out if the floorplan layout could be adapted to the rotation of the twisted tower and even if the façade was not facing south, achieving good light and thermal results.

The student explored three rotations; the result in the figure corresponds to the average of the three rotations. The result is better than the reference solution, proving that when the shape of the building is thought of together with its comfort, the results can be favourable.

As Kolarevic (2005) refers in his book Performative architecture beyond instrumentality, "Perhaps attention to performance will contribute to a new understanding of the ways buildings are imagined, made and experienced. However, this new understanding will not result from developing and deploying new techniques alone. The continued dedication to a technical interpretation of performance will lead to nothing more than an uncritical reaffirmation of old-style functionalist thinking - a kind of thinking that is both reductive and inadequate because it recognizes only what it can predict."

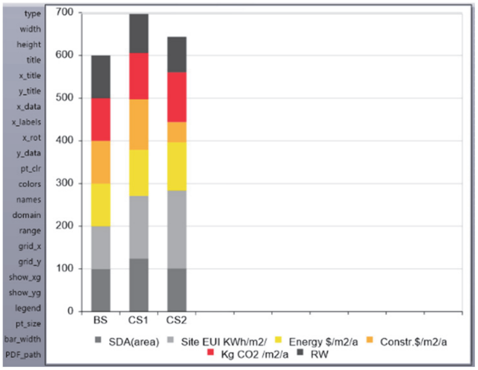


Figure 17
Comparison of the results of the several students solutions regarding a base solution

The two case studies reaffirm this approach towards performative architecture and the advantages of using digital simulation software to grasp the different parameters relating to the performance so that architects can tweak those parameters and come up with multiple project outcomes.

"Then many possible solutions for the problem could be presented, and the selection among them is part of the design process. Having a structure like an algorithm, which describes how the problem is presented and how it can be solved, is a crucial factor for finding the best possible solution." (Kim, Park, 2022)

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