PARAMETRIC DESIGN TOOLS FOR THE DESIGN OF ENERGY EFFICIENT BUILDINGS

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Abstract

Mathematics thanks to the developing technology; the development of computer-aided design technology and act together with a variety of disciplines, including architecture have also been contributing. This relationship has turned into a more complex but also intertwined complex form with the effect of today's developing technology. This change is not limited to topologies or complex geometries. Architecture has integrated the relation between mathematics, geometry, parametric values, logic and various axiomatic applications, parametric values required for energy efficient building design, all methods such as obtaining the desired surface and spaces with parametric values in the concept of computer and design understanding. In today's conditions, mathematics is no longer a tool for the search for proportions and forms for architecture, it has transformed into complex design processes in which the data of different science fields are integrated, and countless data are used as a design parameter, and the basic thinking that these processes need. Different results occur because of different values entered in parameters within the system, which is set up in a virtual environment. These different results are used for form design or for light, sound, and form changes in physical space, as well as for detail solutions and structural system designs. Since every value entered in the model works in conjunction with another formula and equation in the program, if any value is changed, all equations will be updated, so the model is updated and turns into a new result. Scope of work; In the design process of energy-efficient buildings, whose importance has become increasingly important due to climate change and global warming, the features, advantages and disadvantages, sufficient and insufficient points, how the design process works have been investigated. The aim of the study; To comprehensively evaluate and compare parametric modeling programs that require research and analysis on the subject, contain rules and restrictions, and facilitate the transition to trial and error, derivation, and mass production. By examining the criteria that programs need in the early design process, it was examined what data should be investigated before starting energy efficient building design. As a result, the study; Discussing the parametric design modeling and analysis programs used in energy efficient building design and determining the criteria needed by the design process by obtaining detailed information about them, determining which program is needed in which process of the design among the programs. The positive effect of energy efficiency on the architectural design

of buildings is important not only for human life but also for the environment. When designing these buildings, it is important to understand the requirements of the programs correctly to solve the optimization problems with the software developed with the help of technology and to work in terms of the new optimization programs to be produced in the future.

Keywords: Parametric Design, Energy Efficient Buildings, Architectural Optimization

Introduction

Nowadays, with the effect of developing and changing technology, designing with complex geometries has turned into an easier and faster system. Thanks to the relationship between mathematics and computer-aided design technology, the relationship between architecture, mathematics, geometry, parametric values, logic and various axiomatic applications, parametric values required for energy efficient building design, all methods such as obtaining the desired surface and spaces with parametric values in the computer concept and design. has integrated understanding. In this way, mathematics is no longer a tool for the search for proportion and form for architecture, it has turned into complex design processes in which data from different fields of science are integrated and countless data are used as design parameters.

Climate change and global warming, which are the biggest problems of today and the future, have led us to design performance-based energy buildings in the field of architecture. When designing an energy efficient building based on performance, it is possible to obtain different results due to the different values entered in the parameters of the system installed in the virtual environment with parametric design tools.

Parametric-based programs can be used for form design or for light, sound and form changes in the physical space, as well as detail solutions and structural system designs. Since every value entered in the model works with another formula and equation in the program, if any value is changed, all equations can be updated simultaneously, so the model can be updated and transformed into a new result.

Within the scope of the study, the parametric design modeling and analysis programs used in energy efficient building design were discussed and detailed information about them was determined, the criteria required by the design process, and which add-ons to be used in the programs were investigated.

Parametric Design

Keeping up with the development of technology, the designer describes it as a basic need to renew and change design tools to benefit from the benefits of technology. Computer-aided design programs used in architectural design have reached the success that allows the user to make their own path within the system by going beyond their boundaries (Baykara, M., 2011). Returning to the design by trial and error method prolongs the emergence process of the design. Nowadays, it no longer takes time to get back to design with the help of technology. By conducting research and analysis on the subject to be designed with the parametric system design method, it has been possible to find the limited points of the subject and to provide trial and error accordingly and to facilitate the rapid transition to mass production.

Computer is generally used as a representation tool in the field of architecture. Techniques such as orthographic drawing, 3D modeling, animation and graphic drawings in computer environment are widely used as visualization tools to support the traditional design process. In the digital environment, it requires computations, algorithms and, accordingly, algorithmic thinking as well as computer visual thinking. Digital-based design environment has overcome the traditional design environment thanks to the new opportunities it offers. Thanks to the technological innovations brought by today's conditions, the computer, which is not only a visualization tool, has started to be considered as a digital-based design environment.

Leach defines the computer as a powerful tool that provides the design itself (Leach, 2009) and reveals that the success and ability of the architect determines whether the designed product is successful or not. It also emphasizes that parametric design systems can be one of the most successful design methods among tools that can benefit design.

Parametric design is a process based on algorithmic thinking that defines, encodes and expresses the parameters and rules that together define the relationship between the design purpose and the solution suitable for this purpose (Wassim, 2013).

The term parametric is based on mathematics and equations. This equation has certain editable parameters or variables to change the result. Today the term parametric is used to refer to computational design systems. Antoni Gaudí has the first examples of precedents for parametric design, using analog models to explore the field of design in his architectural work. (Frazer, John, 2016).

Antoni Gaudí used analog models to create the feeling of undulating sea and seaweed on the front in Casa Milà, which he completed between 1906 and 1912. Cast iron balcony irons aim to help the wave effect to be perceived more strongly (Picture 1).



Picture 1. Casa Milà- Barcelona, Spain (URL 1).

In the parametric design approach, parameters are associated with other parameters through equations, and changes made in each unit in the model allow the other units to be updated automatically. Simulation of variations interactively in this way is possible by transforming and changing parameters. The ability of a parametric design system to determine and change the geometry of the model is related to the model's dynamically linked parameters (Senagala, 2003). To enter the parameters into the system, it is necessary to know not only architecture but also the information obtained because of an analysis from interdisciplinary relations.

Concept project design, which takes place in the early architectural design process, is the most important part of the design process. When making parametric design, there is a need to link concepts such as program requirements, construction cost, environmental performance, aesthetics, usability, and ecological values to each other by establishing complex relationships and with various limitations in the early design process. While these complex relationships are produced, they are also made possible to make alternative productions in design. Through the main criteria determined in the early design process, more than one design option can be created (Østergård, Jensen, 2015).

The parametric approach, which is the most successful system in creating different design alternatives practically and quickly, can organize and associate data thanks to computer-aided design systems. All the data, values and limitations required to be included in the design through computer aided design systems are within the knowledge of the designer using the program. The designer must enter the numerical data of architecture, mechanics, structure, electricity, landscaping, infrastructure, and all other disciplines required for design into the program used for design through add-on programs. Within the data entered by the designer, the program automatically updates itself and updates the relevant drawings. If the property of any part is changed, all other connected parts are updated in accordance with predetermined rules (Rahmani, 2015).

Drawing tools that do not have an automatic update feature, and changes are made manually, both prolong the process and do not allow interdisciplinary changes. In this context, parametric design tools gain importance. In addition, the most striking advantages of parametric design tools are that the model can be created much faster, precisely and without margin of error. Soumaya Museum, which was built in 2011 using the parametric design system, is the main structure to represent a rotating structural movement and accordingly, while designing the facade, it creates many consoles within the building (Picture 2).



Picture 2. Soumaya Museum / FR-EE Fernando Romero Enterprise, Mexico (URL 2, URL 3).

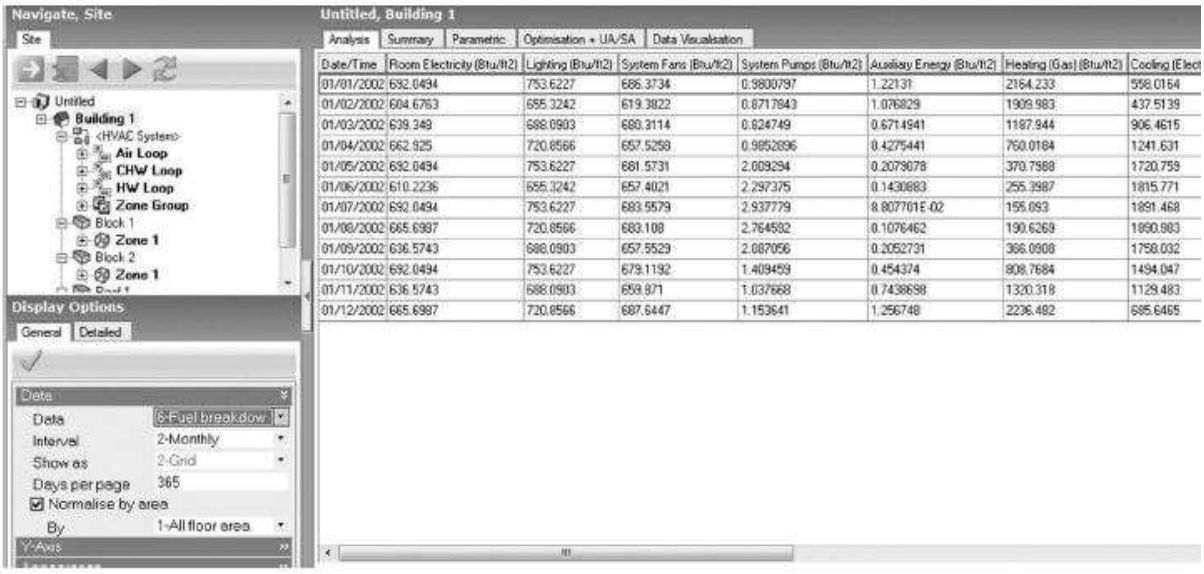
Parametric design systems can be used in every field where design can be transformed into digital data. Designing the form of a building affects multiple design disciplines, such as the formation of a texture for a covering system, the layout, the interconnection of architectural subsystems or an urban design formation (Picture 3). The important point is to introduce the data of the visual and performance-based features expected from the designed product or space to the system.



Picture 3. The Smithsonian Official Building, Courtyard, Washington DC, USA, 2007 by Foster+Partners (URL 4).

It will be made to the data constituting the designed product model an intervention based on experiences and analysis and accordingly, the system reflects the modifications to the model in a fast and competent manner simultaneously, causing the design process to be shortened (Picture 4). The fact that the design system consists of interconnected and interacting data and limitations enables it to incorporate the information that may come from the performance-based program into the system, and to incorporate natural variables such as climatic, geographic, seasonal, and so on into the design. In an architectural design, it is necessary to find the most useful result from the functional point of view with the visuality of the design by analyzing the limitations and information coming from the environmental data and transferring it to the parametric design with a specific system (Baykara, M., 2011).

The fact that basic design factors such as the effect of wind speed and direction on a building, the relation of a land layout with the landscape direction, or the angle of sunlight in the placement of a building's exterior panels, by parametric systems are effective in finding the most successful solution. Parametric systems allow for the change of all values and the simultaneous presentation of design changes that may occur in different scenarios or alternatives to the user (Malkawi, 2004).



Picture 4. Parametric program interface example (Garg, Mathur, and Bhatia, 2020).

Parametric Design and Energy Simulation

Optimization means maximizing or minimizing one or more functions with a possible limitation. The concept of optimization is as old as 300 BC when Euclid explained how the shortest distance between two points is equal to the line connecting them. As simple as the idea could sound, optimization is basically thinking of the best most efficient way to the solution (Priya, Muthulakshmi, 2017).

The goal of optimization is to achieve the optimum solution at all different levels, including energy efficiency, cost, life cycle performance and user comfort. Thanks to optimization methods, designers can avoid extra calculations and consider different solutions such as how to

minimize energy cost without losing temperature comfort. In this way, the most successful one among multiple alternative solutions can be chosen (Lopes, Labaki,2019).

Optimizing energy in buildings is a process aimed to select the best design from a set of possible designs while ensuring that it comply with energy performance requirements. To develop an automated process, optimizing building energy combines simulation-aided design methods and conventional design methods. Energy efficient design optimization technique is used to help architects design buildings with improved energy efficiency and improved performance (Tian et al., 2015). In Freiburg, Germany, 'STADTHAUS M1', which is an exemplary housing project in every aspect, has achieved 30% less heat loss and 70% energy savings by using simulation-aided design methods, focusing mostly on heating (Picture 5).



Picture 5. STADTHAUS M1, Freiburg, Germany (URL 5).

"Smart City Plan Paris", which is one of the future projects where parametric design and energy efficient simulation are designed together, is designed as an ecological project that draws attention to green building designs that will serve many people with the use of innovative smart systems and energy resources. Designing an energy-efficient building using parametric tools provides an opportunity to analyze the results of the scenarios of the buildings to be designed in the future (Picture 6).

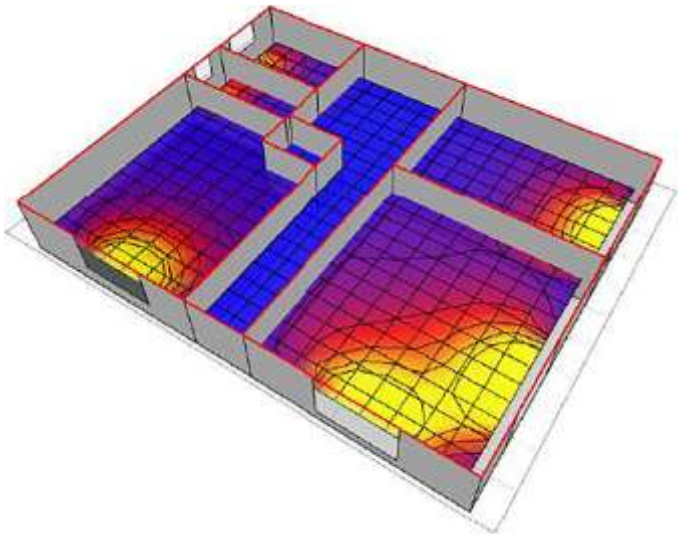


Picture 6. Smart City Plan, Paris (URL 6).

Designing an energy efficient building using parametric tools helps save time and create more accurate calculations and analysis. Parametric design can be used as a tool to assist in different design options, including building form, opening locations and dimensions, materials, and building orientation. It can also be used to analyze the efficiency of different renewable energy technologies to help make decisions based on simulations (Evins, 2013).

To produce an energy efficient building design, there is a need to analyze the energy consumption of the building through its lifecycle. Energy simulation applications are used to model and analyze energy consumption of the design. They could be stand-alone programs that operate separately and need to be fed with the design information to produce simulations or they can be added as a plugin to the main design application (Welle et al., 2011).

Energy simulation can help in making early design decisions, component or material selection and retrofitting decisions. The simulation result in multiple sets of data including tables and graphs. The results are analyzed, and the design is manipulated accordingly (Picture 7). Simulation programs can also provide graphical representations of energy loads and distributions (Lin and Gerber, 2014b).



Picture 7. Computation of Solar Energy Distribution (Ecotect) (Amin H. Al Ka'bi, 2020).

The most used programs produced to simulate energy optimization in buildings are shown in Figure 1.

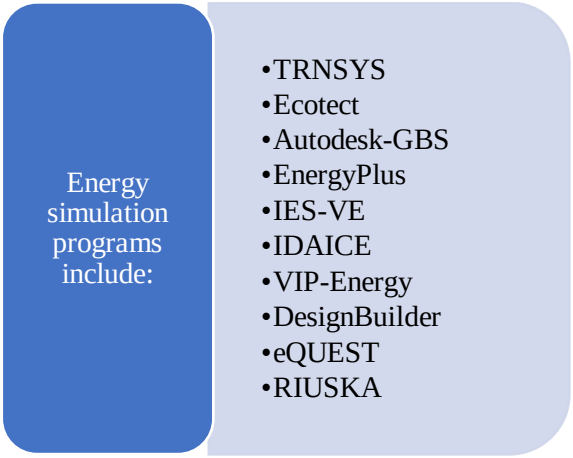


Figure 1. Programs produced to simulate energy optimization in buildings (Tian et al., 2015).

Parametric design usually requires a combination of a design program (Computer-Aided Design [CAD] application or a Building Information Modeling [BIM] application) with a visual programming language software.

The most known software programs that are used for parametric design are Rhino (CAD)-Grasshopper combination and Revit (BIM)-DYNAMO combination. While both are used for parametric analyses, each has advantages and disadvantages that could affect the decision on which tool to use based on the design goals and required analysis and simulations. There are also Generative Component, Digital Project ™ which can be run with CATIA®, GraphiSoft with ArchiCAD (Mousiadis, Mengana, 2016). Typical 3D geometric modeling tools used in architecture are shown in Table 1.

Table 1. Programs produced to simulate energy optimization in buildings (Mousiadis, Mengana, 2016).

The most widely used 3D modeling tools in architecture
Archicad from Graphisoft
Revit from Autodesk
Rhino from McNeel
Maya
Sketchup

Building Information Modeling (BIM) creates a central model that includes all the project components and can be accessed and developed by all the members of the design and engineering team. Revit is the most well-known BIM software. ArchiCAD and BIM 360 are examples of other available BIM software programs (Figure 2).

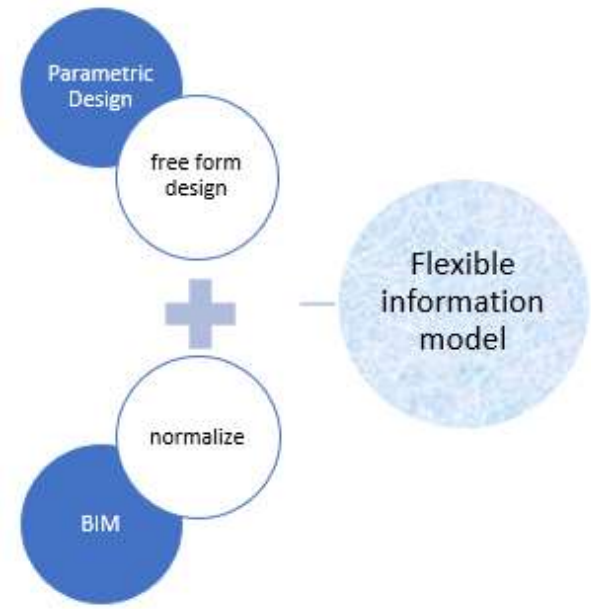


Figure 2. BIM vs. Parametric Design (Wahbeh, 2017).

In energy efficient design, parametric modeling, which uses the Rhino + Grasshopper most, is used to find the most suitable solution for the design. It can be used in energy simulation, integrated with Grasshopper, using plug-ins such as EnergyPlus, Ladybug and Honeybee (Figure 3).



Figure 3. A suggested workflow for parametric based optimization in Grasshopper (Toutou et al.,2018)

Method

Scope of work; The parametric design approach used in the design process of energy efficient buildings, which is increasingly important due to climate change and global warming, and the characteristics, advantages, and disadvantages of the simulation programs in the optimization process were examined.

The aim of the study; It is to comprehensively evaluate and compare parametric modeling programs that require research and analysis on the subject, contain rules and restrictions, and facilitate the transition to trial and error, derivation, and mass production. By examining the criteria required by the programs in the early design process, it was examined which data should be researched before starting energy efficient building design.

Discussion

When parametric design methods in Building Information Modeling (BIM) are examined under the titles of using object-oriented parametric modeling, parametric approach in conceptual design environment and visual programming, it is seen that they cover the features in Table 2.

Table 2. Parametric Design methods within Building Information Modeling (BIM) (Wahbeh, 2017).

Using Object-Based Parametric Modelling	**The Parametric Approach Within Conceptual Design Environment**	**The Visual Programming**
✓ Using Predefined Elements Within the Project ✓ Approach with Limited Parameters ✓ Architectural Elements in BIM Have Standard Limitations and Predefined Criteria	✓ Graphical geometry-based ✓ Ability to create models that can define variables and constraints directly in geometry ✓ Close to the classical CAD concept but it supports the addition of constraints	✓ Can generate scripts without restrictions ✓ Associated with algorithmic modeling tools ✓ Allows to define all three ✓ Content data of a model's variables, constraints and relationships.

Parametric design usage stages for better energy performance are shown in Figure 4.

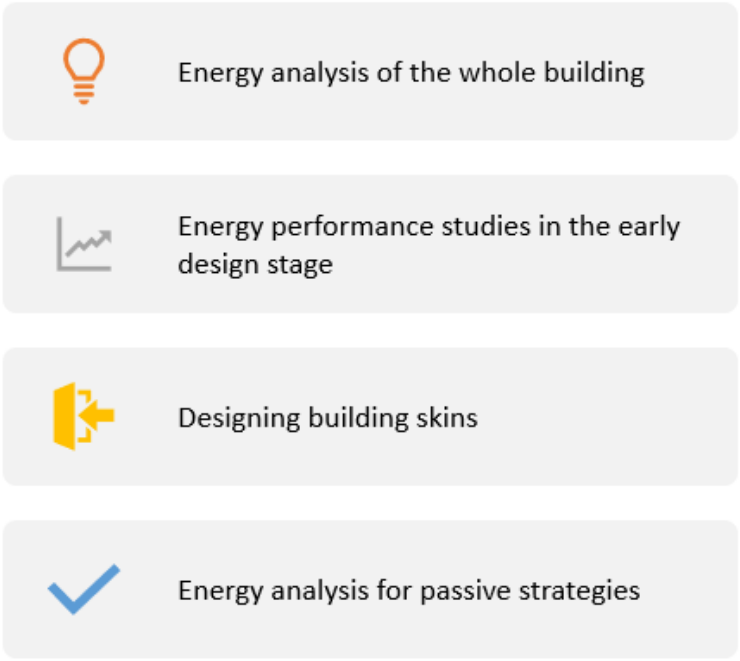


Figure 4. Parametric design fields of use for better energy performance

When the possibilities of Building Information Modeling (BIM) and parametric design are evaluated separately and evaluated together, the result is as in Figure 5.

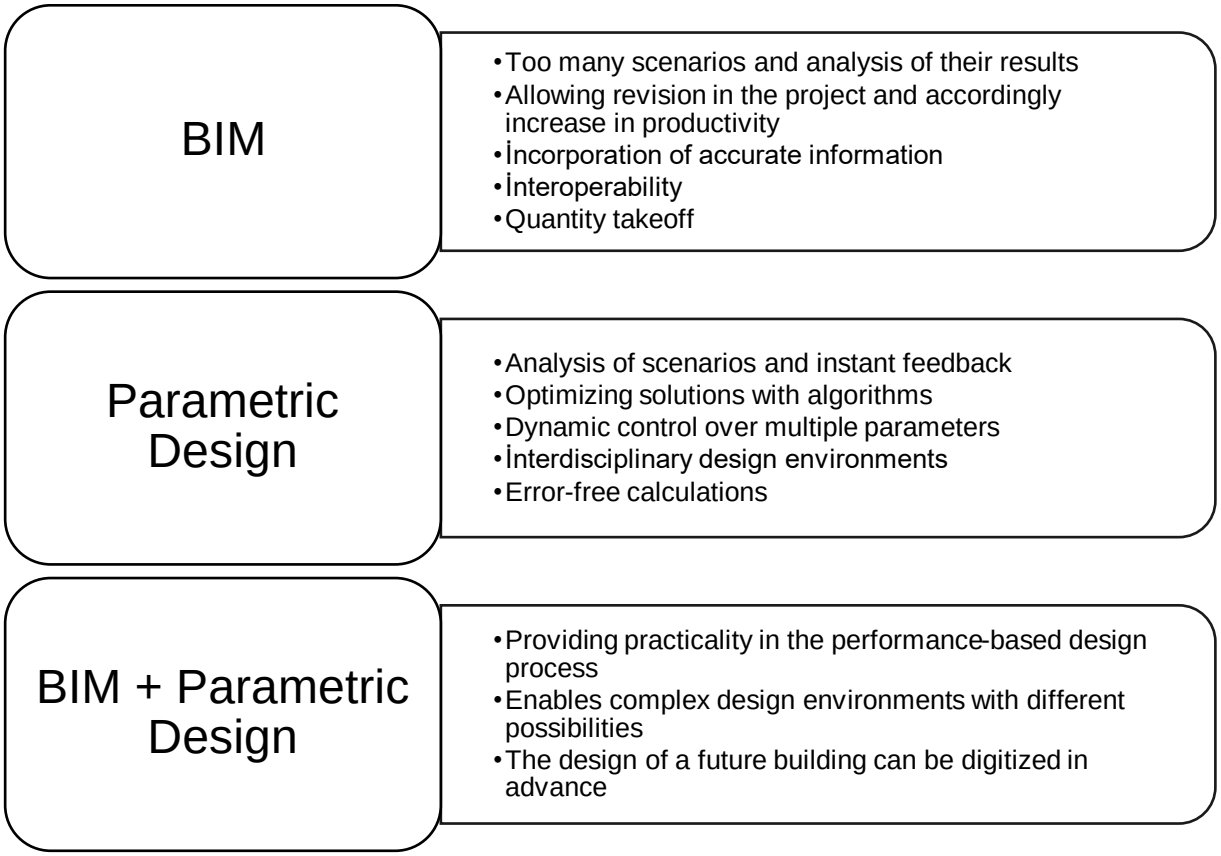


Figure 5. BIM vs. Parametric Design, BIM + Parametric Design (Zardo et al., 2019).

In addition to evaluating the possibilities of BIM and parametric design separately and evaluating them together, the comparison, which includes the general characteristics of Dynamo and Grasshopper performance simulations, which are most used for energy simulation, can be seen in Figure 6.

Category	Dynamo	Grasshopper
Interface / design	Aesthetically Inferior	Colorful, Beautiful, Light
Functionality / performance	• Operates in a native BIM environment, broader potential for use through interoperability • Less functional, confusing for beginners, difficult to find functions. • Greater ability to manipulate existing projects • Best suited to professional practice (Revit is widely used for construction projects)	• More robust, easier to use, compact • Handles the native software less (rhino) • Better in morphology, shape design, but difficult to share with BIM architecture, data is not "understood" by native software
Resources	• Built-in function to locate and publish user-developed component libraries • Educational license (3 years)	• More tool options (Galapagos, Karama, Kangaroo, Ladybug, Diva) • Less frequent updates • 90-day trial license for rhinoceros

Figure 6. Dynamo vs. Grasshopper (Zardo et al., 2017).

Conclusion

As a result, the study; discussing the parametric design modeling and analysis programs used in energy efficient building design and determining the criteria needed by the design process by obtaining detailed information about them, determining which program is needed in which process of the design among the programs. The positive effect of energy efficiency on the architectural design of buildings is important not only for human life but also for the environment. When designing these buildings, it is important to understand the requirements of the programs correctly to solve the optimization problems with the software developed with the help of technology and to work in terms of the new optimization programs to be produced in the future.

The advantages provided by computer aided design programs that are developed and updated in line with the users' purposes; with its form and structure, it enables different and assertive parametric designs to be modeled in digital environment, to visualize the design more easily and to simulate physical processes.

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