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Design Approaches of Parametric Kinetic Wall Systems: Innovative Architectural Solutions

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ABSTRACT

Parametric design is an approach that expands architectural practice and changes traditional perceptions. This method allows architects to balance functionality and aesthetics using algorithmic thinking in the design process. Kinetic architecture involves the design of structures and buildings that often move in response to environmental conditions. The use of parametric design in conjunction with kinetic architecture enables the design of buildings to respond quickly to dynamically changing conditions. This study focuses on buildings designed with parametric design and kinetic architecture approach. Its conceptual background is based on written sources, internet databases, analyses and photographs. Rhinoceros-Grasshopper, one of the most widely used programmes of the parametric design process, was used as a method. Parametric algorithms were used to design a kinetic wall with this program. As a clear result, it has been observed that the mathematical algorithms provided by parametric design and the ability of kinetic architecture to move can provide innovative solutions in architectural design very quickly.

Parametrik Kinetik Duvar Sistemlerinin Tasarım Yaklaşımları: Yenilikçi Mimari Çözümler

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ÖZET

Parametrik tasarım, mimari pratiği genişleten ve geleneksel algıları değiştiren bir yaklaşımdır. Bu yöntem, mimarların tasarım sürecinde algoritmik düşünceyi kullanarak işlevselliği ve estetiği dengelemelerine olanak tanımaktadır. Kinetik mimari, genellikle çevresel koşullara yanıt olarak hareket eden yapıların ve binaların tasarımını içermektedir. Kinetik mimari ile birlikte parametrik tasarımın kullanılmasıyla yapıların tasarımlar, dinamik olarak değişen koşullara hızlı bir şekilde cevap verebilmesini sağlamaktadır. Bu çalışma, parametrik tasarım ve kinetik mimari yaklaşımıyla tasarlanan yapılar üzerine odaklanmıştır. Kavramsal alt yapısında yazılı kaynaklar, internet veri tabanları, analizler ve fotoğraflar temel alınmıştır. Yöntem olarak, parametrik tasarım sürecinin en yaygın kullanılan programlarından birisi olan Rhinoceros-Grasshopper kullanılmıştır. Parametrik algoritmalar, bu yazılımla kinetik bir duvar tasarımı yapmak üzere kullanılmıştır. Sonuç olarak, parametrik tasarımın sağladığı matematiksel algoritmalar ve kinetik mimarinin hareket edebilme yeteneği ile mimari tasarımda çok hızlı bir şekilde yenilikçi çözümlerin sunulduğu görülmüştür.

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INTRODUCTION

Parametric design is an approach that expands the boundaries of architectural practice and changes traditional perceptions. This approach allows architects to balance functionality and aesthetics by using algorithmic thinking in the design process (Jabi, 2013; Şekerci and Yıldız, 2020).

Kinetic architecture is closely associated with concepts such as mobility, geometry and location; such buildings or building elements can be defined as an architectural style characterised by changeability. Compared to traditional architecture, this approach emphasises the changeability and mobility of buildings over time, rather than a fixed form (Maree, 2007; Çakır, 2021).

This study focuses on designs designed with parametric design and kinetic architecture approach. The flexibility of parametric design and the dynamic nature of kinetic architecture are analysed and evaluated through various examples. Then, the stages in the design process are emphasised with an example of a kinetic wall designed with parametric algorithms.

Objective and Importance of the Research

This study focuses on the design approaches of parametric kinetic wall systems and innovative architectural solutions. After the conceptual background is established, a moving wall design is made using parametric modelling techniques. At the beginning of the design, the parameters are defined, the relationships between the parameters are constructed and the design is realised through the algorithm created.

The main objective of the study is to understand the design process of kinetic wall systems using parametric modelling techniques and to evaluate the potential of these systems in architectural applications. In this direction, the algorithmic principles of parametric design and the features of kinetic architecture that provide the balance between aesthetics and functionality are explained through the design process.

Methodology of the Research

The methodology of the study is based on written sources, internet databases, analyses and photographs for conceptual background. Visuals and examples were used to provide detail. In the design phase, 'Rhinoceros-Grasshopper' software was used as a method and a parametric kinetic wall was designed. A design concept was created for the wall, which was considered as a parametric design element, which will be a combination of function, space, form, aesthetics-beauty, composition and ecology-sustainability concepts.

In addition, within the scope of this design process, the functionality of the wall was increased by utilising the flexibility and innovation opportunities provided by parametric design and a building element that improves both user experience and environmental performance was developed.

Scope and Limitations

In this study, a kinetic wall design application using parametric algorithms is discussed. In this design, other variables such as physical environmental conditions (such as sun, wind, humidity), mobile users (human or animal) are excluded as parameters.

Only Rhinoceros-Grasshopper software was used in the design process. Rhinoceros-Grasshopper is the most basic programme based on parametric modelling and evolutionary algorithms and works with NURBS (Non Uniform B-Splines) surface logic. The NURBS surface logic is less developed in other programmes used for the same purpose. However, the fact that this program works with precise and accurate values and that parametric data and energy calculations can be made on the same interface are the criteria that are effective in choosing it as the most suitable program for the study (Yazar and Uysal, 2016).

The study theoretically focuses on the aesthetic and functionality dimensions of kinetic architecture.

LITERATURE REVIEW

Kinetic Architecture and Importance

Kinetic architecture, unlike traditional architecture, offers an innovative approach to design by combining motion mechanics with advanced technology. While traditional architecture primarily emphasises formal stability and staticity, kinetic architecture changes this understanding and focuses on moving and variable forms. This feature enables buildings to go beyond merely presenting a fixed visual appearance and to interact more dynamically with their surroundings. Stan (2006) and Al-Juboori (2021) state that kinetic architecture redefines architecture both functionally and aesthetically as a system sensitive to environmental changes.

Kinetic architecture stands out as a system that can adapt to variables such as environmental factors and usage needs. While such buildings offer important advantages such as natural light control, ventilation and energy saving, they can also improve the user experience. The concept of kinetic architecture, introduced by Zuk and Clark (1970), combines technology and engineering to enable buildings to dynamically adapt to changing conditions. Al-Juboori (2021) emphasises that such buildings make a significant contribution not only in terms of aesthetics and functionality, but also in terms of environmental sustainability.

The basic concepts of kinetic architecture include mobility, geometry and location. Maree (2007) stated that kinetic architecture, unlike traditional architectural approaches, creates forms that can change and move over time. Çakır (2021) stated that kinetic architecture has the ability to respond flexibly to user needs and environmental conditions with a variable structure instead of a fixed form. In this context, kinetic architecture offers solutions to both individual and social needs with moving building elements.

Innovative approaches such as kinetic architecture not only provide energy efficiency, but also set an example in terms of aesthetics and environmental sustainability.

Hymavathi et al (2022) have approached the contributions of kinetic architecture to energy efficiency and sustainability from a broad perspective. It is stated that kinetic systems reduce the need for mechanical systems with features such as natural light control and natural ventilation, thus reducing the carbon footprint. It is also emphasised that these systems offer significant advantages in terms of safety by optimising evacuation routes during emergencies. This shows that kinetic architecture makes great contributions not only to environmental conditions, but also to human safety and user experience.

Akgün et al (2022) focused on the aesthetic value of kinetic structures and stated that moving surfaces give the building a dynamic visuality. Such surfaces work in an ever-changing harmony with their surroundings, offering elements that enrich the user experience in both individual and public spaces. The dynamic structure of kinetic architecture transforms architecture from a static object into a system that can respond directly to the needs of users and environmental changes.

As a result, kinetic architecture offers an innovative design approach by combining the basic requirements of modern architecture such as aesthetics, functionality and environmental sustainability. With the combination of motion mechanics, advanced technologies and creative design approaches, kinetic architecture not only responds to today's needs, but also opens a path with the potential for further application in the field of architecture in the future. The work of pioneering researchers such as Stan (2006), Zuk and Clark (1970) formed the basis of kinetic architecture, and today this understanding has been enriched with new Technologies

Parametric Design, Principles and Importance

Parametric design is an approach developed by integrating algorithmic thinking into architectural design unlike traditional design processes. Jabi (2013) states that parametric design offers architects the opportunity to develop both functional and aesthetic solutions by controlling design parameters. This method offers a modelling process structured through parameters and the relationships between these parameters in the design process. The basic principle of parametric design is that design elements are defined by algorithms and work dynamically within an interconnected system. This feature enables designers not only to create forms but also to analyse how the design will change under various scenarios (Erdoğan & Sorguç, 2011).

Traditional architectural design usually has fixed geometries and limited flexibility. However, parametric design makes the design process more flexible and dynamic. Thanks to the relationships created between the parameters, a change made in one design element can affect all other elements. This offers an important advantage not only in terms of aesthetics but also in meeting functional requirements. For example, the parametric design process can be used to optimise the energy performance of a building or to create a structure that will adapt to environmental conditions (Chu, 2006).

An important advantage of parametric design is that it provides the opportunity to quickly evaluate different solutions during the design process. In this way, designers can choose the most appropriate design alternative by working on more than one scenario. Erdoğan and Sorguç (2011) state that parametric modelling is an important tool for imitating natural forms and applying sustainable design principles. For example, biomorphic designs can be created by transferring the forms and systems found in nature to architecture through parametric modelling. Such approaches not only offer an aesthetic value, but also meet energy efficiency and sustainability goals by taking inspiration from nature (Knippers et al., 2012).

With the development of digital tools, parametric design has transformed not only the architectural design process but also the performance analyses of buildings. Software such as Grasshopper, Rhinoceros and Dynamo allow designers to manage and optimise complex geometries. Şekerci and Yıldız (2020) describe how parametric design is used to assess the impact of different materials and spatial arrangements, particularly in interior architecture practice. This approach provides a powerful tool to make users' interactions with space more efficient and provide more sustainable solutions.

Another important dimension of parametric design is its integration with the construction process. Digital production techniques can directly transfer the flexibility provided by parametric design to physical structures. Maree (2007) states that digital production processes increase the potential of parametric design, enabling the creation of more complex and innovative structures.

The application areas of parametric design are not limited to architecture; this method is also used in different disciplines such as landscape design, urban design and product design. For example, it is known that parametric design is used in many projects of Zaha Hadid Architects. In these projects, the contributions of parametric design in terms of aesthetics, functionality and sustainability are clearly seen. There are also numerous examples of how parametric modelling processes have been used to optimise building systems such as natural lighting, ventilation and energy performance (Monticelli, 2015).

The importance of parametric design is not only limited to flexibility and innovation in the design process; this approach also stands out as a tool that improves the performance of the building and facilitates the achievement of sustainability goals. Knippers et al (2012) state that combining parametric design with innovative approaches such as biomimicry and kinetic architecture facilitates the adaptation of buildings to environmental conditions.

Parametric design is an approach that maximises the creative potential of architects and designers and transforms modern design processes. This method, which meets both aesthetic and functional requirements, plays an important role in achieving contemporary design goals such as sustainability and performance optimisation by transcending the boundaries of traditional architecture.

Parametric Kinetic Wall Systems

Kinetic wall systems, as dynamic structures in which mechanical and electronic components are integrated, refer to variable and flexible facade systems that can adapt to environmental factors in the construction sector. The working principle of these systems is to ensure that the structures can move beyond being static, depending on environmental conditions or user needs. The technical components and working principle of parametric kinetic wall systems are as follows:

Mechanical Systems: Kinetic walls usually work with moving parts such as motors, pulleys, gears, rails and hinges. These elements move the wall or facade elements in desired directions. For example, a facade can be opened or closed by means of sensors sensitive to sunlight. This is used to control the indoor temperature (Çabuk, 2024).

Electronic and Automation Systems: Kinetic walls use sensors, actuators and computer-based control systems to react to environmental variables. These sensors measure external factors such as light, temperature, wind speed and process data on how the system should act. For example, if the sunlight is too high, a section of wall can be opened to provide natural shading indoors (Şansal and Üce, 2019).

Structural Components: The materials used in kinetic facades are generally flexible, durable and lightweight. Strong but lightweight materials such as steel, aluminium and composite materials are preferred. In addition, fabrics or glass panels used in the construction of these structures are generally designed to be resistant to external factors (Çabuk, 2024; Kahramanoğlu and Alp, 2021).

Visual Aesthetic and Functional Aspects: These systems offer significant advantages both functionally and aesthetically. Structures not only respond to the needs of the user, but also become aesthetically interesting from the outside. For example, the movement of the walls both makes the structure functional and creates a visually dynamic effect (Şansal and Üce, 2019).

Kinetic wall systems are used in various areas to adapt to environmental changes, increase energy efficiency and combine aesthetics and functionality in various areas. Areas where these systems are used:

Residential and Commercial Buildings: Kinetic walls can be used in homes and commercial buildings. The dimensions of the living spaces can be changed according to the different needs of the users. Sunlight-sensitive walls can increase the comfort of the interior by opening and closing according to the time of day and season (Çabuk, 2024).

Public Spaces: In public spaces such as parks, shopping malls, amphitheatres, kinetic walls offer visitors an interactive and dynamic experience. Such structures are also aesthetically striking and adapt to the environment. For example, kinetic systems used outdoors adapt to the environment by offering changing shapes and functions according to the weather (Şansal and Üce 2019).

Sports Facilities and Stadiums: In spaces such as large sports halls and stadiums, kinetic walls are used to optimise indoor airflow and light levels. This increases energy efficiency and improves the user experience, especially in large indoor spaces. In addition, these systems can be shaped according to the capacity and utilisation of the space (Kahramanoğlu & Alp, 2021).

Museums and Exhibition Areas: Kinetic walls offer a flexible design in museums or exhibition spaces and can control light, temperature and airflow. This helps to better present exhibitions in exhibition spaces and improve the visitor experience (Güvenli, 2021).

Kinetic walls have the ability to change shape in response to environmental influences, creating both aesthetic and functional differences. The importance of kinetic walls in architecture stems from the fact that architectural design has become more dynamic and interactive. These walls provide architects not only aesthetic benefits but also environmental sustainability, energy efficiency and user interaction.

These walls can increase the energy efficiency of buildings as they can move according to environmental conditions. For example, wall panels can position themselves according to the position of the sun to receive sunlight in the most efficient way. Likewise, wind walls can naturally cool the interior of the building by changing shape according to the wind direction. Such systems increase sustainability by reducing energy consumption and contribute to the construction of environmentally friendly buildings. In this context, kinetic walls are an important tool in ‘green building’ design (Kibert, 2016).

Kinetic walls have aesthetic and dynamic design possibilities, unlike fixed structures, they offer a dynamic visual experience. These walls enable architecture to go beyond being just a building and offer an ever-changing visual experience to the viewers. In this respect, kinetic walls have an aesthetically important place in modern architecture (Burry and Burry, 2010). In addition, the building creates a new experience space by interacting with its users. The movement of users on the walls can cause these surfaces to change, so that the interaction of individuals with spaces becomes more intense. Furthermore, kinetic walls can also improve the interiors of buildings. Walls can improve the quality of interior spaces by controlling environmental factors such as light, airflow or sound (Dalton et al., 2016).

These walls encourage innovative design approaches in architecture. They offer architects the opportunity to overcome the traditional understanding of fixed walls and make their buildings more flexible, interactive and environmentally friendly. Kinetic walls can transform not only building functions but also social and cultural meanings (Pallasmaa, 2024).

The Role of Kinetic Walls in Architectural Applications

Kinetic walls stand out as structures that can move and adapt to environmental conditions and user needs in architectural applications. Such building elements offer various advantages in modern architecture by combining aesthetics and functionality. Kinetic walls also increase indoor comfort by reacting to environmental changes. For example, a kinetic wall can move according to sunlight and let in natural light or prevent overheating. This flexibility saves energy by maintaining the temperature balance inside the building (Akgün et al., 2022).

Kinetic walls also offer functional advantages in emergency scenarios. Especially during evacuation, moving walls can speed up the evacuation by regulating the flow of people. Thus, while increasing building safety, it also positively affects the user experience. In addition, kinetic walls can also be used as urban furniture. However, today, it is mostly used as a building element that forms the building envelope. Kinetic walls redefine traditional architecture by offering architects freedom of design. These systems allow buildings to not only fulfil functional requirements but also to flexibly adapt to the needs of users and environmental conditions. The role of kinetic walls in architectural applications provides multifaceted benefits such as using energy more efficiently, increasing user comfort, promoting safety and providing aesthetically innovative solutions (Hymavathi et al., 2022).

User Interaction and Performance of Kinetic Walls

Kinetic walls provide a two-way interaction with the users, transforming the building from a static to a dynamic structure. This approach allows users to adapt the space according to their needs. Walls that monitor user behaviour and change position when necessary reveal that users actively interact with the building components. This kind of interaction defines the building as a flexible structure that responds to user needs rather than a fixed environmental element (Hymavathi et al., 2022).

Kinetic walls provide surfaces that users can directly interact with. This interaction can be realised by changing the shape of the wall when a person comes into contact with it or performs a certain movement. Users establish a physical connection with the space by making the walls open, close, bend or move. Kinetic walls can open or close depending on whether users step on them or touch them, thus creating a transformation in the space. Such interactions remove the boundaries between the building and the user, creating a more participatory and interactive experience (Dalton et al., 2016).

Kinetic walls create not only visual but also physical and sensory interaction. Users can feel the change of sound or temperature differences in the air as the walls change shape. These interactions both enable users to play a more active role in the space and strengthen their connection with the physical environment. Such sensory experiences enrich the atmosphere inside the building and involve users more deeply in the space (Zeng, Liu & Liao, 2020).

In addition, the performance of kinetic walls is directly related to user interaction. These structures are systems that can quickly adapt to the needs of users. When the temperature inside a building increases, kinetic walls can be opened to optimise air flow. Similarly, the walls can change position according to the time of day in order to receive sunlight in the most efficient way. Such adaptations increase the comfort of users, provide energy efficiency and improve the performance of the space (Burry and Burry, 2010). At the same time, it allows users to take a more active part in the space and this positively affects the user experience. Being in a dynamic environment strengthens individuals' sense of belonging to the place. When users have the power to change the environment, these interactions become more meaningful. The performance of kinetic walls allows users to feel more comfortable and free in the space, while increasing social and physical interaction within the building (Zeng, Liu & Liao, 2020).

Examples of Kinetic Walls Designed with Parametric Tools

Kinetic walls, especially in modern architecture, are used to increase the environmental sensitivity of buildings, save energy and offer an aesthetic innovation. Kinetic walls also enhance the users' experience of the space and transform architecture from a static structure into a dynamic organism. Thanks to advancing material technologies and digital control systems, these systems are becoming smart solutions that improve both the performance and visual appearance of buildings. Kinetic walls, which combine functionality and aesthetics, are mostly used as the building element that forms the building envelope today. Therefore, examples of the use of kinetic walls as facade elements are selected and described below:

The Dynamic Tower- Dubai, United Arab Emirates

Designed by architect Ar. David Fisher and is notable for the ability of each floor to rotate independently. This building aims to revolutionise architecture by using today's modern technologies. In the project's design, each floor of the building rotates using motors and can change shape according to environmental conditions and user preferences. These rotating floors create a unique and dynamic appearance for the building (Figure 1), (Kibert, 2016), allowing the facade of the building to constantly change. The ability of each floor to rotate 360 degrees makes the physical structure of the building highly flexible. This feature allows users to control the interior spaces of the building. Users can change the view inside the building and regulate the angle of sunlight. In addition, the building's ability to rotate allows the exterior surface of the building to change according to environmental factors such as temperature and wind. This helps to optimise the energy efficiency of the building and increases the environmental sensitivity of the architecture (Kibert, 2016).

Figure 1
The Dynamic Tower (URL1)

The Dynamic Tower is one of Dubai's iconic buildings and one of the most ambitious and innovative examples of kinetic architecture. In this project, the traditional fixed structure concept in architecture has been challenged, enabling each floor to rotate independently. This dynamic feature is both aesthetically and functionally revolutionary. The Dynamic Tower goes beyond being just a building, transforming architecture into an organism that interacts with time and environmental conditions. The Dynamic Tower is one of the most advanced examples of kinetic architecture. Kinetic architecture refers to structures that react to environmental factors and can physically change shape. This design approach reveals the idea that architecture is not limited to fixed and static structures, but can offer a dynamic and changing experience. The Dynamic Tower embodies this concept, using high-tech motors that enable each floor to rotate independently. In order for each floor to rotate, various systems and technologies that increase energy efficiency are integrated in the building. The rotational movement of the floors is supported by renewable energy sources such as solar panels and wind turbines, enabling the building to generate its own energy. In addition, thanks to the rotating structure of the building, the interior spaces can be instantly adapted according to user needs, which increases the flexibility of the building (Kibert, 2016). The building significantly improves energy efficiency as it can change shape depending on environmental factors. Each floor rotates to optimise sunlight, allowing the interior spaces to be illuminated with natural light. Furthermore, the building's façade changes shape according to the direction of the wind, allowing the efficient use of wind energy. This minimises the energy needs of the building and makes it an environmentally friendly building (Kibert, 2016).

Cactus Towers- Kopenhag, Danimarka

Cactus Towers is located in the Vesterbro district of Copenhagen and is designed as a complex combining three different towers. These towers form a dynamic structure that accommodates various residential and office spaces to meet the requirements of modern life (Figure 2). This is a modern building in Denmark, which demonstrates the aesthetic and functional aspects of kinetic architecture. This project is an important example not only in terms of architecture but also in terms of sustainability and environmental awareness. Cactus Towers stands out with its dynamic façade design that responds to environmental factors, innovative building materials and integration with nature. (Kolarevic, 2003).

Figure 2

Cactus Towers (URL2)

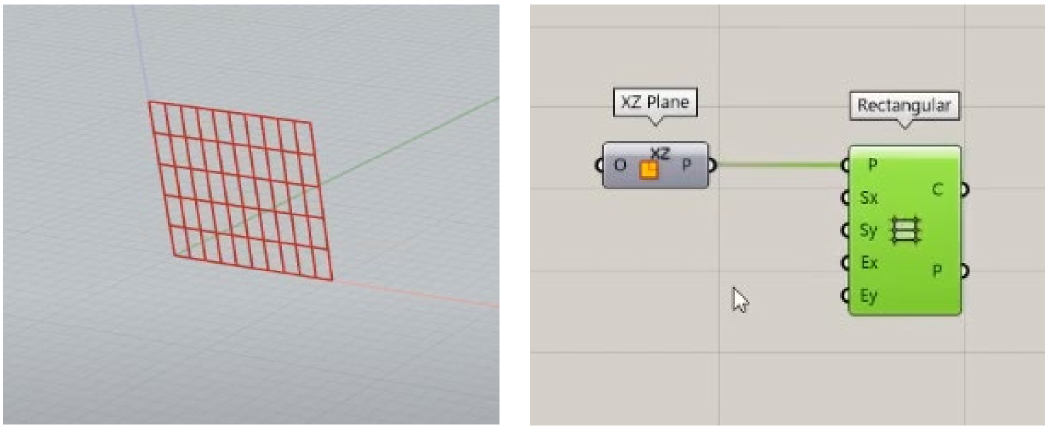
Cactus Towers utilises elements of kinetic architecture to create a building that can adapt to environmental conditions. The movable panels on the exterior of the building change shape according to sunlight and air currents. These panels are designed to provide energy efficiency in the interior spaces of the building. Especially by filtering sunlight, they protect the interiors from overheating and allow natural light to enter more efficiently. Furthermore, the kinetic walls are designed to increase the comfort of the building users, reacting to environmental conditions to maintain the internal temperature balance of the building. This design allows users to establish a more interactive connection with the building, while at the same time creating a more resilient and flexible structure against environmental influences (Kolarevic, 2003). Cactus Towers incorporates numerous innovative practices in terms of sustainability. This project not only provides kinetic walls and environmental adaptation, but also incorporates various energy efficiency measures to minimise environmental impact. The building minimises energy consumption through the use of solar panels, rainwater harvesting systems and other renewable energy sources. The use of environmentally sensitive materials also reinforces the project's sustainability approach. Such materials help to utilise natural resources more efficiently while improving the energy performance of the building. Furthermore, structures designed to provide natural ventilation and thermal comfort significantly reduce the environmental impact of the building. Cactus Towers is of great importance not only from an aesthetic and environmental point of view, but also in terms of social interaction. As the project is located close to Copenhagen's city centre, the towers create both comfortable living spaces and a social hub for the surrounding communities. The building is designed with a variety of functions, such as offices, commercial spaces and residences, making it a dynamic living space. Cactus Towers makes the city stronger both socially and environmentally and aims to create sustainable communities (Burry and Burry, 2010).

DESIGN APPROACHES OF PARAMETRIC KINETIC WALL SYSTEMS: INNOVATIVE ARCHITECTURAL SOLUTIONS

Parametric design allows us to create dynamic and flexible structures through the use of various parameters and algorithms. This process is well suited for designing moving, interactive and adaptive features of kinetic walls.

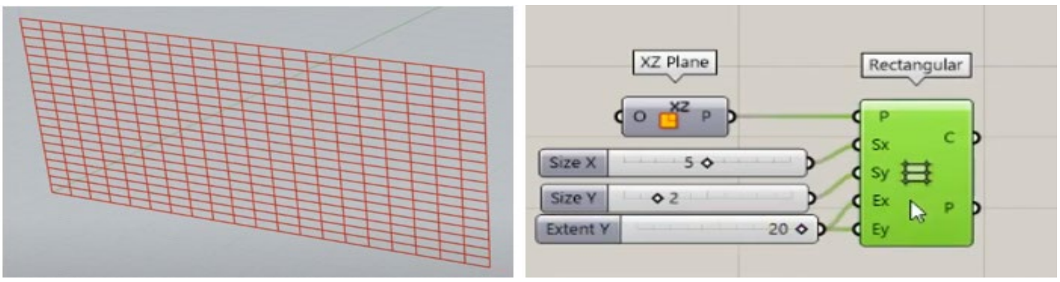
Parametric tools provide a powerful method to optimise the aesthetic and functional properties of kinetic walls. Firstly, a plane in the XZ plane was created in Grasshopper and the Rectangular command was entered to create a grid (Figure 3).

Figure 3
Kinetic Wall Design Step 1 (Screenshot Saved by the Author)



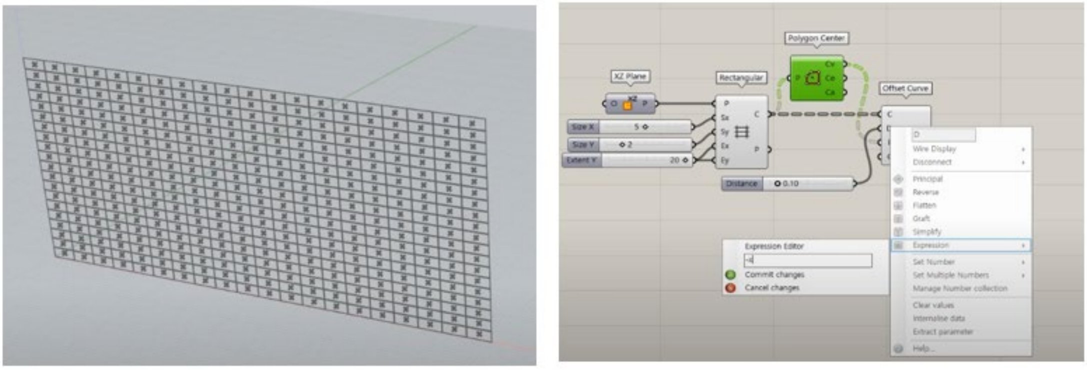
Size X, Size Y, Sx, Sy and Extent Y parameters were used to determine the dimensions of the grid, number of cells and cell sizes. A rectangular grid with an X direction with 5 cells and a Y direction with 2 cells and a width and height of 20 units was created on the plane (Figure 4).

Figure 4
Kinetic Wall Design Step 2 (Screenshot Saved by the Author)



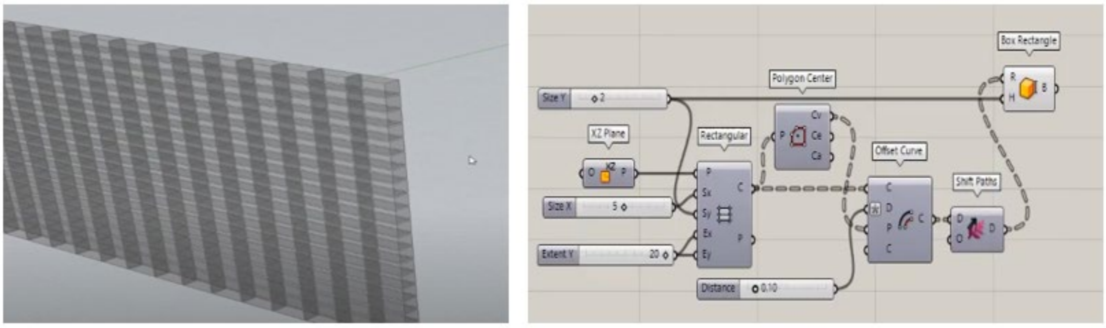
With Polygon Center, the centre of each cell is determined, these centre points are the reference points for the movement or deformation of the cells. Using the Offset Curve command, an offset curve is created at a certain distance from the centre. Right click on the Offset Curve box and enter the Expression Editor (-x) value and select Commit Changes, this is a structure that determines how the curve will take shape (Figure 5).

Figure 5
Kinetic Wall Design Step 3 (Screenshot Recorded by the Author)



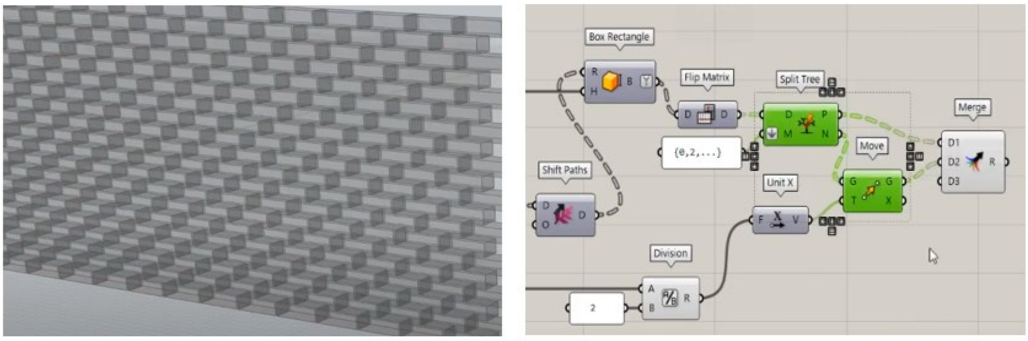
Shift Paths This command affects how data is processed by shifting the data paths. With this command, a different movement was applied to each cell. Then, with Box Rectangle, the panels were transformed into three-dimensional boxes. These boxes represent the final shape of the wall (Figure 6).

Figure 6
Step 4 for Kinetic Wall Design (Screenshot Recorded by the Author)



With the Flip Matrix command, the matrix of the data is flipped, i.e. the rows and columns are swapped. Then the data tree is split into branches with the Split Tree command, this operation is used to select the branches of a given data set. The Shift Paths command is used to switch the position of the components in the data structure, shifting the paths in the data tree by a specified number. Division is used to divide by a numerical value. This step is used to control the displacement of different parts of the wall. The Move command was added to move the boxes in the direction of the vector provided by Unit X. Finally, the Merge command was used to merge all the data for the final output (Figure 7).

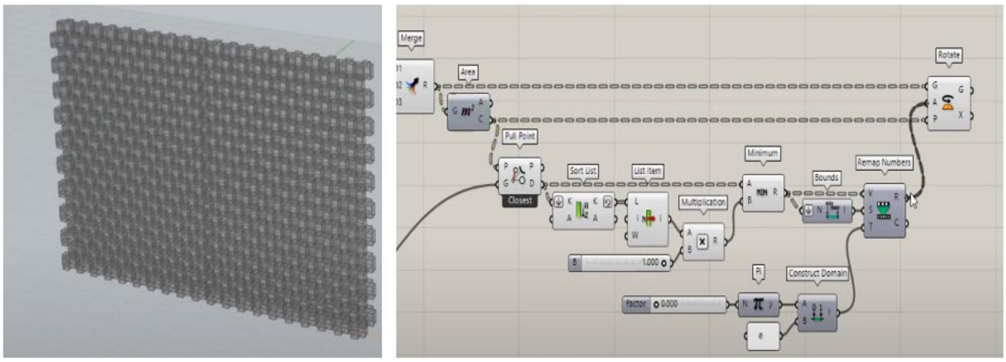
Figure 7
Step 5 for Kinetic Wall Design (Screenshot Saved by the Author)



Area command is used to provide information about the dimensions and centre of mass of each module. Pull Point command is used to create a dynamic movement around a point. The Sort List command determines the order of movement and rotation of the modules. Then the List Item command is added and the operations to be performed on the module (rotation, movement) are controlled from here.

With Multiplication, the amount of movement and rotation of the modules is determined. Minimum command is added by entering the required value to limit the movement and rotation of the modules. The Bounds command is used together with the Remap Numbers command to rescale the data range and keep it within a certain limit. Then the Construct Domain command was added to determine the boundaries of the values used for rotation and movement. With Rotate, the modules are rotated around themselves at a certain angle. Factor and Pi are used to determine the angle for rotation and Pi is used to calculate a value in radian (Figure 8).

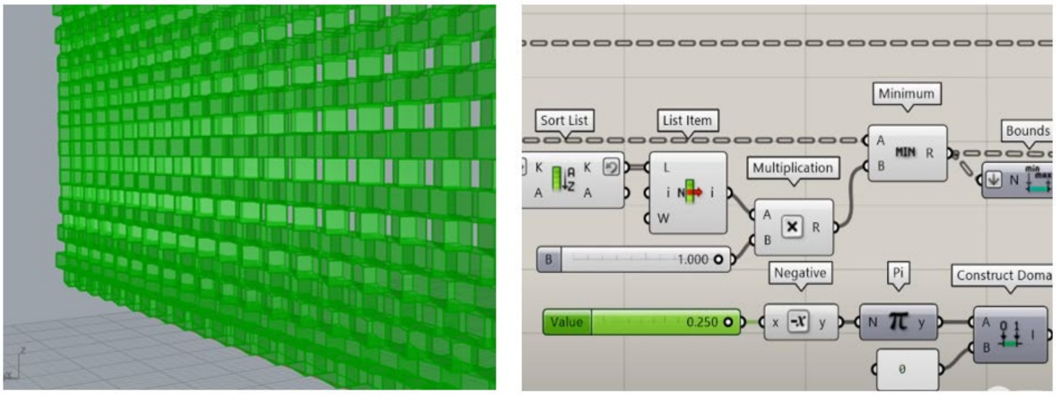
Figure 8
Step 6 for Kinetic Wall Calculation (Screenshot Recorded by the Author)



With Sort List, the data list is sorted according to a certain criterion. With the List Item command, certain modules are selected on which the movement and rotation operations will be performed later. Multiplication command was used to determine the amount of movement and rotation of the modules. Minimum and maximum parameters in the database were determined using the Bounds command. With the Negative command, the direction of rotation and movement of the modules was reversed.

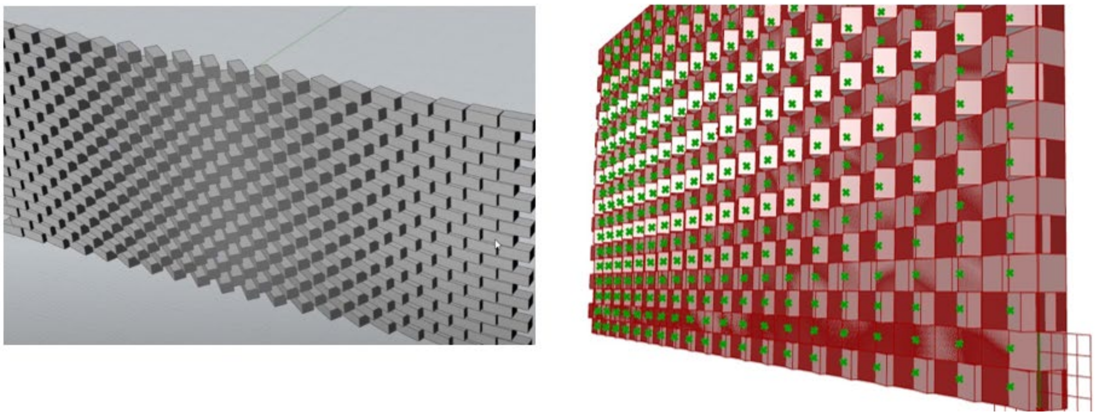
Value Slider is used to control the amount of movement and rotation angle of the modules. Pi is used to calculate the rotation of the modules in radian and therefore the number Pi is used to calculate the rotation angle. Finally, Construct Domain was used to determine the movement and rotation range of the modules (Figure 9).

Figure 9
Step 7 for Kinetic Wall Design (Screenshot Recorded by the Author)



Thus, a kinetic wall design was achieved using parametric algorithms (Figure 10).

Figure 10
Kinetic Wall Design (Screenshot Recorded by the Author)



CONCLUSIONS AND RECOMMENDATIONS

Kinetic walls designed with parametric algorithms are important to increase user comfort. These structures, which can adapt to environmental conditions, provide a more comfortable and healthy environment indoors by effectively controlling natural light. This adaptive feature ensures that factors such as light and temperature are at optimum levels during the time users spend in the space. Kinetic structures offer a dynamic experience by interacting with the user and the building becomes a living environment rather than a static object (Hymavathi et al., 2022).

Esthetically, parametric kinetic walls give the building a unique and dynamic visual value. Moving surfaces or form-changing facades allow the building to present an aesthetic that is both harmonious with its surroundings and ever-changing. This not only enhances the visual appeal of the building, but also enriches the user experience. Because the space is constantly reshaped depending on different conditions and creates a unique experience for users (Akgün et al., 2022).

The role of kinetic walls in architecture is highly valued for their versatile contributions in areas such as energy efficiency, user comfort, safety and aesthetics. Combined with high technology and digital control systems, these structures not only provide functionality and sustainability, but also represent an innovative approach in modern architecture. These dynamic building elements prevent overheating of interior spaces by filtering sunlight and allow the effective use of natural lighting. Providing a balanced temperature in the interior reduces the dependence on air conditioning. While the energy consumption of the building is significantly reduced in this way, energy costs are also reduced thanks to these automatic systems. The reduction in energy consumption, especially in the summer months, also contributes to the reduction of the carbon footprint of the building (Hymavathi et al., 2022).

Kinetic walls contribute not only to energy efficiency but also to environmental sustainability by increasing the comfort of users. By opening and closing the kinetic panels, a natural air circulation can be achieved, which allows natural ventilation. Thus, the need for mechanical ventilation and cooling systems is reduced. In summary, kinetic walls and facade systems not only reduce building energy costs, but also offer a smart and environmentally friendly architectural solution that contributes to the environmental sustainability of buildings in the long term (Hymavathi et al., 2022).

Parametric kinetic walls also provide great benefits in terms of architectural safety and emergency management. In cases such as emergency evacuation, kinetic walls increase safety by allowing people to exit the building quickly and safely. Especially in densely populated areas or large buildings, the use of kinetic walls in roles such as opening or guiding evacuation routes makes the evacuation process more efficient (Johnson et al., 2019).

In this context, this study describes the design process of kinetic wall systems using parametric modelling techniques and evaluates the potential of these systems in architectural applications as facade elements. According to this scope, conceptual infrastructure was created and kinetic wall design was performed using parametric modelling algorithms. At the beginning of the design, the parameters were defined, the relationships between the parameters were constructed and a very fast and easy design was realised by using Rhinoceros- Grasshopper software through the created algorithm. As a result, an adaptable façade character that can effectively control natural light has been revealed. In terms of aesthetics, thanks to its moving surfaces, there is a dynamic facade formation far from monotony. At the same time, it offers a unique experience to users with a constantly renewed spatial perception.

As a suggestion within the scope of the study, in order to further improve the performance of kinetic walls, the walls can be integrated with sensors that can detect environmental conditions. In addition, more comprehensive research can be conducted on the environmental sustainability of kinetic walls. In particular, it is important to examine in depth the environmental impacts of kinetic walls related to the production, maintenance and material selection.

Kinetic walls are a powerful tool to meet the basic needs of modern architecture such as sustainability and user interaction. Supported by technological advances, kinetic structures make a significant contribution not only in terms of energy efficiency and aesthetics, but also in terms of safety and environmental sustainability. Therefore, kinetic walls offer an innovative solution with the potential to be more widely utilised in future architectural designs.

Author Contributions

Research Design (CRediT 1) Author 1 (%20) – Author 2 (%80)

Data Collection (CRediT 2) Author 1 (%60) – Author 2 (%40)

Research - Data analysis - Validation (CRediT 3-4-6-11) Author 1 (%50) – Author 2 (%50)

Writing the Article (CRediT 12-13) Author 1 (%60) – Author 2 (%40)

Revision and Improvement of the Text (CRediT 14) Author 1 (%00) – Author 2 (%100)

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Conflict of Interest

The authors declare no conflict of interest.

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