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The Implementation of Cellular Automata in Shading System "South Oriented Facade -Case Study"

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ABSTRACT

With the obvious substitution of the natural environment with the artificial environment and the inevitable solar heat gain in the Mediterranean climate, energy-efficient facades must be considered in buildings. This paper explores Cellular Automata (CA) as a strategy for retrofitting existing façades with green integrated shading systems optimized for south-oriented office space in the Mediterranean Climate of Alexandria. It is considered a contribution to optimizing daylighting performance and creating a more pleasant indoor environment. The main novelty of this paper is the attempt to use the generative design approach to implement a membrane over existing facades with integrated vertical greens. The paper analyzes the daylight simulations of the studied space using Diva-for-Rhino to pinpoint the best locations for green surface utilization. Then various Cellular Automata patterns are evaluated to select the possible rules for applying the green integrated shading systems. The designed façade performance is then analyzed through the suggested criteria. To explain the positive impact of the retrofitting, a comparative analysis of the findings is concluded together. To conclude this approach can be employed as a tool by interior designers to enhance indoor quality and the visual impact of the interior space.

KEYWORDS: Cellular Automata, Fractals, Vertical Garden, Green facade, Sustainability, Generative system.

1. INTRODUCTION

The paradigm shifts toward computational technologies have facilitated the design exploration for architects [1] and allowed for various solutions using multiple iterations to reach the optimal performance required. This approach, where the performance requirements are assessed alongside the geometry of the

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building or building envelope, is called ‘Generative Performative Design’ [2]. Using an algorithm-driven process contributes to the conduction of multiple variations beyond the scope of human imagination [3]. The usage of Cellular Automata as a Computational Generative System provides huge variations of design solutions. However, without conducting suitable stimulations using advanced simulation tools, promising results will not be achieved [1].

The emerging technology of the ‘Generative Performance Design’ approach can be implemented on building envelopes, where results follow the required performance [1]. A few researchers have discussed the integration of Cellular Automata to generate façade design. For example, [3]the usage of new hourly-based metrics to integrate illuminance and energy evaluations of a cellular automata-controlled dynamic shading system. Other attempts were explored by who explored the use of Dynamic shading of a building envelope based on a rotating polarized film system controlled by one-dimensional cellular automata in regular tessellations (triangular, square, and hexagonal) [6]. The integration of Cellular Automata to provide optimum daylight requirements has been suggested by Zawidzki M [4,5 and7]. The form generation for the BE used in these examples is generated with daylight as the performance criteria and CA as the generative design system.

None of the previous research explored the possibility of using the Cellular Automata combination to integrate Green Façade design and how it can further contribute to optimizing daylighting performance. This study aims to design green integrated shading systems optimized for south-oriented office space in the Mediterranean Climate of Alexandria, Egypt, using a Cellular Automata (CA) driven method. The generative quality of Cellular Automata can be used to produce different alternatives as the forms are defined by a set of rules with constant numbers providing multiple alternatives.

This paper comprises six sections. The first is an introducing discussion about two key topics which are the previous conducted research on computational systems and vertical green systems. The second section is a literature review that in topic those both systems. The third section showcases two successful examples and analyze them to provide the criteria used to choose the designed façade. The fourth section presents a case study based on MIT office space. This section covers all the settings, evaluation criteria and quantitative analysis of Cellular Automata by rule classification and selections that were employed. The results and discussion appear in the fifth section, which focuses on the chosen design that proofs the concept that Cellular Automata can be integrated with vertical green to create a balanced system of the three cores of design which are visual continuation, functionality, and environmental aspects. The simulation results are compared to present optimal design scenarios that serves the three cores of design. The study ends with the conclusions, which integrates Cellular Automata with green façade together correctly that could be used as a model for researchers to further apply.

2. LITERTURE REVIEW

2.1 Previous Studies on Vertical Green Systems

Building envelopes are considered one of the essential architectural parts of any building and is considered the key element where architects can express their uttermost creativity [5]. Nevertheless, the aesthetic qualities of the design are given the most accreditation, which drastically limits the potential of improving the performance of the building. Apart from being the link between interior and exterior environments, where the visual continuation and natural light between the two can be either provided or concealed, a building envelope can make the users feel secure in the internal environment and protected from the outdoor environment, such as noise pollution, temperature, humidity, glare, etc. [5]

Given that urbanization has caused the severe substitution of the natural elements with the artificial environment, the building envelope can play a pivotal role in enhancing the human-nature connection once again [8], especially in office spaces where there is a particular need to maintain specific heat and thermal comfort throughout the year [9]. Designers always face the dilemma of using transparent materials on façades to provide an unobstructed external view or using opaque materials to limit the solar heat gain in the interior spaces [10,11]. Due to all the previous causes, there is a need for a shift in building envelope design towards a more sustainable option without compromising the view and enhancing the crucial needed link between humans and nature once again.

2.2 Types of Vertical Green Systems

Vertical green walls can be implemented in several ways, ranging from growing from the ground up to being embedded in the façade. These systems are known by several names, including the green wall system, the living green system, the green façade system, etc. [12]. Nevertheless, given these green walls can be categorized into two main sectors according to many factors, including their installation and maintenance, the design approach used, the vegetation used, and the structure system used as well [15]. The implementation of these systems is generally categorized into nine main sectors, whether artificial or natural [13]. This section previews a summary of these systems and how they can be used. Nevertheless, given the modern architectural shift, a vertical garden could be more relevant [14]. For proper implementation, the designer should know the difference between these two major systems: green walls and Living walls shown in Table 1 through a comparative analysis between these two systems.

2.2.1 Green facade

The vegetation by nature can grow either upwards in a climbing motion or downwards in a hanging motion, and these abilities contribute to the Green Facade design. A green façade can be classified into two major direct or indirect systems [16].

- Direct greening system:

Some plants have extraordinary attachment quality that helps them stick to the required walls without using a structure system to support them. The growth of these plants initiates from the roots, either in the soil or its planters [17,18].

- Indirect greening system:

As much as they are more economically friendly, the adhesive qualities require specific types of plants. The other type of plant cannot stick to walls and surfaces; therefore, a structure system should be used to facilitate the growth of the plants in certain areas and circulation. The initiation of the growth can be either from the soil base or planter base, just like the direct green system. These types of plants require the addition of rooting spaces such as a prominent planter at the bottom or multiple planters along the height of the wall for the primary purpose of minimizing inconsistency in the vegetation along the wall resulting in a more homogeneous appeal [18]. The extra façade on the existing building can act as a double skin and contribute to further reducing energy consumption. The air gap between these two layers acts as an energy diffusor, given its slower diffusion rate [16]. Various systems have been used in the past years, yet the most renowned are using wire and cable net systems [18], using mesh systems made from metal [19], and using modular trellis panel systems [18,19].

2.2.2 Living Walls:

With a more sophisticated infrastructure and various attaching methodologies, living walls have been widely used as an environmentally aware material in the past years [16]. The main difference between living and green walls is that living wall roots are attached to a substrate on the wall itself instead of being planted in the ground [17]. Given the fact that the roots are spread over the façade, a more consistent elevation is presented. In addition to adapting to different geometries and typologies, living walls can cover larger areas than green walls. Living walls can be categorized into two systems: continuous and modular [20].

Fig. 1 showing a summary of different vertical green systems Source: Researchers.

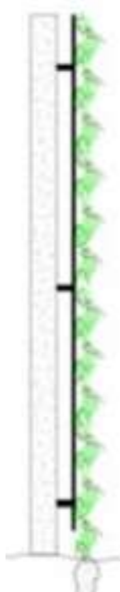
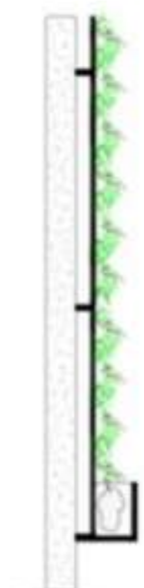
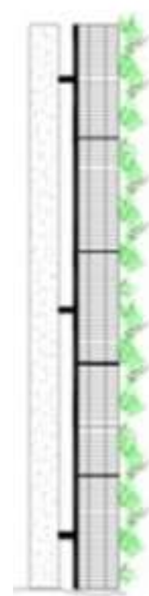
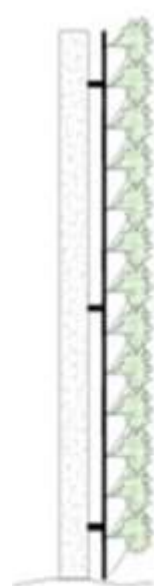
- Continuous system

Patric Blanc previously introduced the vertical living mat wall, a French landscape designer, when he created “le Mur vegetal” [18]. The system consists of a padded surface that acts as a media that can stimulate plant growth. The surface is then attached to a waterproof surface to protect the walls from the water supply for the plants [21]. The used padding system can be considered a hydroponic system as they provide the plants with nutrients and water needed [19].

- Modular system

Modular living walls present some differences from the continuous system given its difference in assembling the wall, how the wall can be composed and how much it weighs. Modular containers can have various forms with different stacking strategies, giving them flexibility beyond any other system. The container can be further divided into smaller units with various stacking geometries [19]. Since these used panels were planted before implementation, they give an instant change to the whole aesthetics of the façade. Even though they require constant watering, they can hold much heavier plants. Figure 1 presents a summary of these suggested systems with visual images representing each system individually.

In this research, Modular systems are chosen given that they represent various sizes that can be reflected as Cellular Automata cells. This presented flexibility results in having the required façade solid and void ratio. This research suggested using geometrical planter tiles from the various forms that can be used in this system. This design would further suggest integrating lighting units in the geometrical planters highlighting the proposed CA façade at night.

Green facade	**Living Wall**
Planted in the ground.	Attached to a substrate on the wall itself.
 	 
Grow upwards in a climbing motion or downwards in a hanging motion.	Adapt to different geometries and typologies.
Less consistent elevation is presented	More consistent elevation is presented

Require specific types of plants and cover less area	Cover larger areas.
Classified into two major systems: direct or indirect.	Categorized into two systems: continuous and modular.
	

Table. 1 Comparison between Green Facades and Living Walls. Source: Researchers.

2.3 Previous Studies on Cellular Automata

Given its remarkable computational capabilities, Cellular Automata is used as a generative design system [6]. Generative design systems are categorized into five main systems: Swarm Intelligence, Shape Grammars, L-Systems, Generic algorithms, and mainly Cellular Automata [22]. The multiple iterations produced contribute to endless possibilities expanding the architectural realm beyond imagination. As individual elements, Cellular Automata cells are simple, yet when combined, they create a homogenous system that can have multiple purposes later. This phenomenon is called 'the emergence' [23]. How homogenous the system is acts because of how each individual cell is interconnected with the one next to it, and how the cell reacts in the following line corresponds to its neighboring cells. The application of CA is divided into three main parts: modeling, simulation, and optimization. These impressive properties should be explored and implemented in architecture design instead of limiting the scope to previously known systems [24].

Cellular Automata exploration commenced in the 1930s when von Neumann's research showed how the self-reproduction of cells could produce homogenous systems. The research aimed to study the cells' duplication and growth in a mechanical assembly along with the issues concerning the modeling of these growing systems. The use of arrays using computational methodologies was then proposed, resulting in the creation of the first CA automated system ever [25]. It was further developed a decade later when high-speed processing was introduced [26]. As time passed, the CA system was further developed until it was the most successful computational system that proposed a very dynamic and changing system [27]. Throughout the years, CA has been profoundly known to be used in specific applications. For instance, creating an illumination system [27], designing prototypes that can be used as shading systems, and creating educational toys [28].

Designing buildings with biological and organic qualities are relevant to creating dynamic and integrated systems and having those biomimetic qualities results in having dynamic control over façade systems. Along with having emergence qualities, the system's modularity adds to the list of advantages in implementing them. To be able to implement a Cellular Automata façade, specific criteria should be taken into consideration. The criteria should include the aesthetic quality of the used Cellular Automata pattern, the balanced density of the cell's combination ranging from transparent to opaque, and the gradual transition between both cells to present the organic appeal of this system which is the uniform division of cells on the façade.

3. Example Analysis

The novelty of this research lies in applying Modular Living Walls to the homogeneous properties of the Cellular Automata system to create an environment that is not only aesthetically pleasing but also functional and environmentally friendly. Furthermore, two examples—Cellular Automata and Vertical Green Systems—are examined, each representing a different aspect of the proposed design. The Arab World Institute is analyzed in the first case as it is the most well-known Cellular Automata-induced example. This example demonstrates how implementing the Cellular Automata system into practice can reverse the irregulates that existed prior to implementation. The implementation of vertical gardens on bare walls in Limassol is the second analyzed example where it aimed to enhance users' quality of life with a minimal level of interventions. Table 2 explains the analyzed example selection criteria that is based on location, climate zone and design considerations.

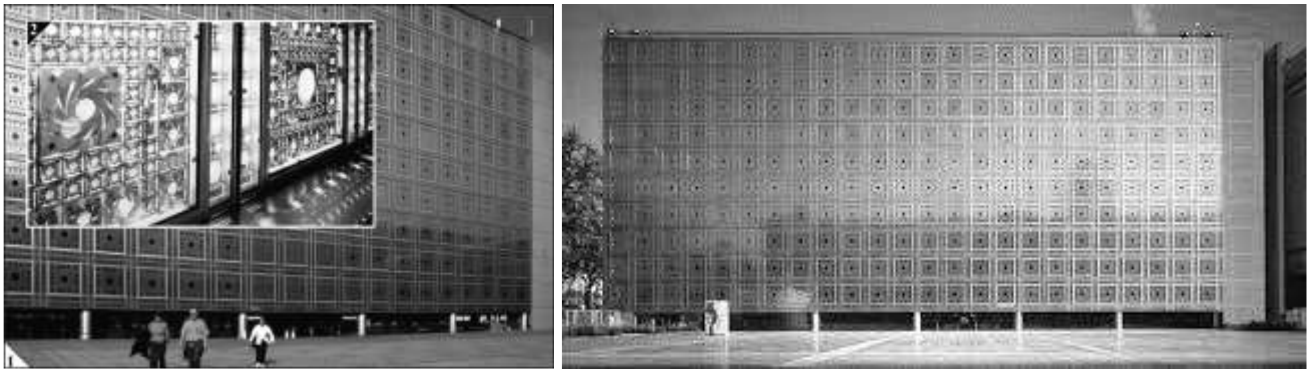
Selection Criteria	**The Arab World Institute**	**Implementation of Vertical Gardens on Bare Walls**
Location	Paris, France	Limassol, Cyprus
Climate Zone	Temperate Zone	Mediterranean Zone
Design Considerations	▪ Located in the southern part of the temperate zone as most of France fall. ▪ The location falls under the effect of the Mediterranean Sea in the south. ▪ Cellular Automata grid and unique quality.	▪ Located in under the effect of the intense Mediterranean climate. ▪ Located in a Dense environment where there is an inability to add greenery to the urban environment. ▪ Cellular Automata design approach.

Table. 2 Examples Selection Criteria. Source: Researchers.

3.1 An example of adaptive building envelope: the Arab World Institute

In Paris, France, the building façade of the Arab World Institute (AWI) was divided into an array of 20x10 metallic cells and implemented as a dynamic system in 1987. As a method of controlling daylight in the interior of the building, the cells used were divided into a multilayered dynamic system that opens and closes with respect to the daylight factor. Consequently, the building presents a unique aesthetic quality [6], as shown in figure 2.

Even though the building envelope is aesthetically pleasing, errors have been reported since its implementation. The complexity of the mechanism used to control the multiple layers of the cells resulted in a high margin of error. They contributed to the building having decorative quality, compromising the functional one. However, this example is considered a recognizable turning point in the application of dynamic façades, where there has been a commendable effort to implement the concept of integrating the interior environmental qualities presented in the daylight factor. That appeared in the interior aesthetic qualities presented in the interesting shadows created and the exterior visual qualities presented in the dynamic façade [27].



(a) (b)

Fig. 2 (a) shows Arab Word Institute's CA shading system Detail and 2 (b) shows Arab Word Institute's CA shading system Elevation. Source: [4,27].

By observing biological systems and analyzing them, the errors found in the AWI can be avoided, and a homogeneous system is created. Research has shown that cellular automata can be used to create a consistent shading system called Cellular Automata shading system [4]. The first line is controlled by dividing the façade into an array of cells, and the growth is controlled by the selected rule [27]. This system enables the façade to be controlled constantly yet can be adapted by changing certain factors in the used algorithm, giving numerous varieties to the designer and the architect.

3.2 An example of adaptive building envelope: Implementation of Vertical Gardens on Bare Walls, Case Study Area: Limassol, Cyprus

Located in the heart of Limassol, due to the concentration of environmental issues presented in this area, this research focuses on pinpointing areas where green elements are diminished. The chosen site is analyzed, and buildings are categorized based on typology, level of greenery in the surroundings, and level of environmental pollution. With the variety of buildings and circulation modes presented on the site, different pollution levels have been available.

Fig. 3 shows the living wall implemented in Cyprus Source: [29].

Dense environments showed the inability to add greenery to the urban environment. However, the availability of bare facades provided an alternative solution to the lack of green elements on the site. The main aim was to improve users' quality of life with minimal interventions. Green elements in dense urban areas act as a breather in the urban environment. It respects users' circulation on the site, dwindling the unbearable search for a void in the urban fabric [29].

A vertical and horizontal grid is implemented on the bare walls that act as a structure for the greenery to grow [29]. Materials used range from wooden connectors and plastic covers to steel cables and hubs. Based on the intensity of the greenery needed, the grid varies in density and cell dimension.

These two analyzed examples provide the criteria used to choose the designed façade. The inconsistencies in The Arab World Institute require a homogeneous system that can be created using Cellular Automata. While Dense environments in Limassol showed the inability to add greenery to the urban environment, which can be solved using Cellular Automata. The following section discusses the integration of these systems and the final proposed design.

4. CASE STUDY

This research aims to answer the question of whether the integration of Cellular Automata generated green façade can contribute to better daylight performance in the interior space of the office room. In order to to achieve good results, this section is divided into five parts: a reference office model, evaluation of the room prior to screen implementation using a simulation program, screen modeling, rules generation algorithm, and simulation that leads to the comparison between the different outcomes. Based on the literature review, a one-dimensional Cellular Automata pattern was chosen to create the façade of the office building. Simulation is carried out in different scenarios: before façade implementation, façade without greenery, and façade with greenery. This is based on the fact that simulation should be conducted to test the generative design's validity [1]. The space is parametrically modeled in Grasshopper, as well as the rule generation and daylight evaluation.

4.1 Reference Office Model

Based on the MIT reference office space explained and set by Reinhart et al. (2013). The reference office model has been parametrically modeled in grasshopper with the dimensions of: 8.20 in length, 3.60 in width, and 2.80 in height, as shown in figure 4 and figure 5.

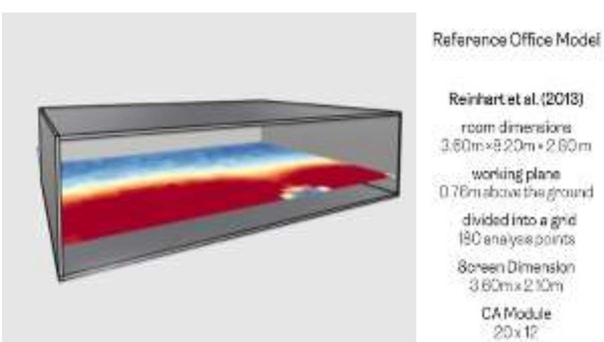


Fig. 4 Reference Office Model. Source: Researchers.

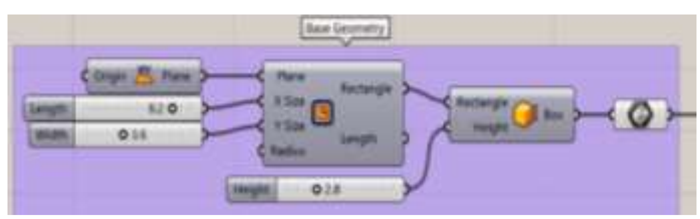


Fig. 5 Parametric Modeling of space in grasshopper Source: Researchers.

Regarding the office's working plane, which is positioned 0.76m above the ground level, the grid is placed at this level and divided into 180 grid analysis points. This southern-oriented façade is located on the ground floor in the Mediterranean climate of Alexandria, Egypt.

4.2 Screen Modeling

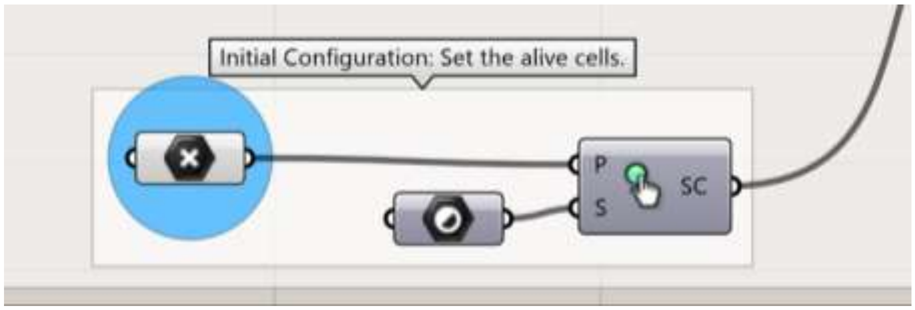


Fig. 6 Conditions of the Time zero set Source: Researchers.

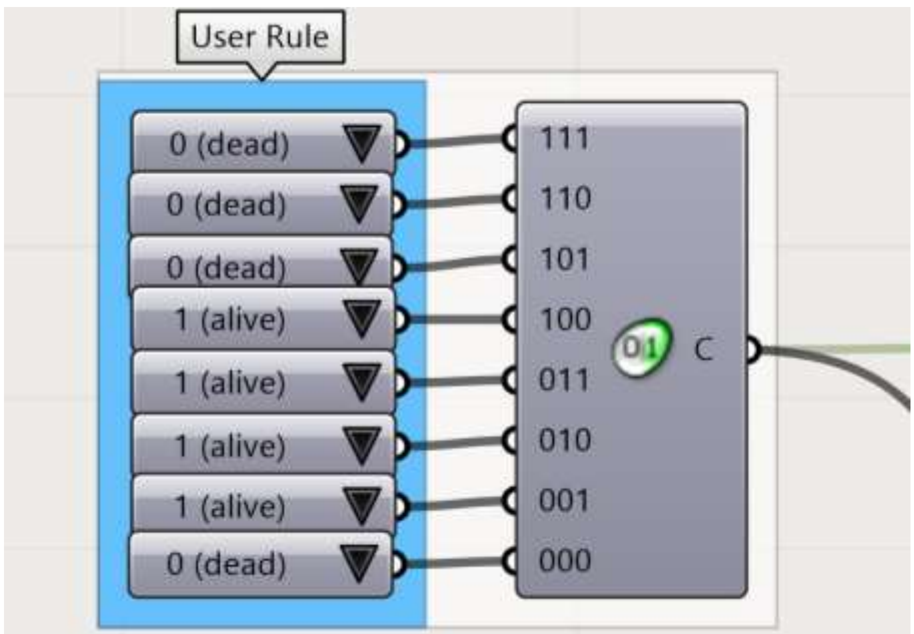


Fig. 7 Rules Applied Source: Researchers.

The generative design of one-dimensional Cellular Automata was modeled using the Morphcode plugin in grasshopper, and the conditions for the time zero are set as shown in figure 6. That method follows the logic of having an array of cells in a square geometry with each cell holding certain information, whether On or Off, One or zero, Black or White. Based on each cell’s neighboring cells and following selected rules, they adapt and change for specific steps at a time [6]. An initial state of the cell is chosen at the time zero (t=0). The state of each cell at that time was the base of the choices. Figure 7 explains that as time increases, the applied rule influences the shape of the next time step.

That means that the initial state of the cell has the most transformative contribution to the whole structure. Cellular Automata is determined by three main factors, the dimension of the cell (D), what is the state of each cell (K), and the Radius (R), as mentioned by [6]. Figure 8 shows the cell's evolution over time based on selected rules S.

Fig. 8 Cells evolution over time based on selected rules Source: Researchers.

Since each cell holds certain information, these data determine the green and glazed façade locations. The Black cells represent the green façade, and the White cells represent the glazed façade, as shown in figure 9. This allows for unlimited variations of vertical gardens that can contribute not only add to the aesthetic appearance of the interior and exterior of the building but also can be optimized for the best daylight performance.

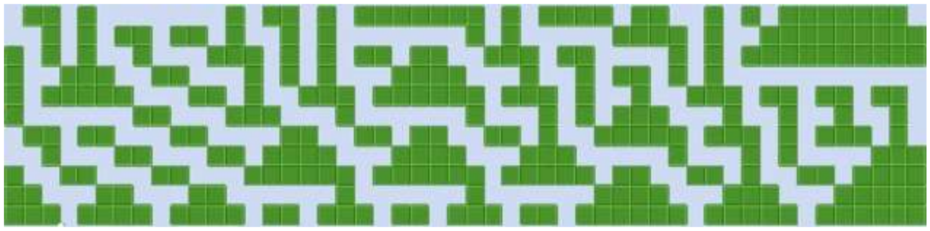


Fig. 9 Replacing Black Cells with Green Façade Source: Researchers.

4.3 Rule Selection

To be applied as shading applications, the selected one-dimensional Cellular Automata rule should have a certain repetitive quality. These criteria are available in 18 Cellular Automata rules, as suggested by [4]. As shown in Figure 8, the randomly Optimal Rules for shading application Source [4] set black cells in the first-time set could manage the rest of the time sets. Therefore, the opacity level remains constant from the first time set till the last one required [1]. This results in an outstanding contribution to creating a fully integrated green and glazed façade with ratios that create an aesthetically pleasing geometry and an optimal indoor daylight quality. Rule 210, as shown in figure 11, was chosen to conduct this research given the interesting qualities it represents and tested according to the Mediterranean climate of Alexandria, Egypt.

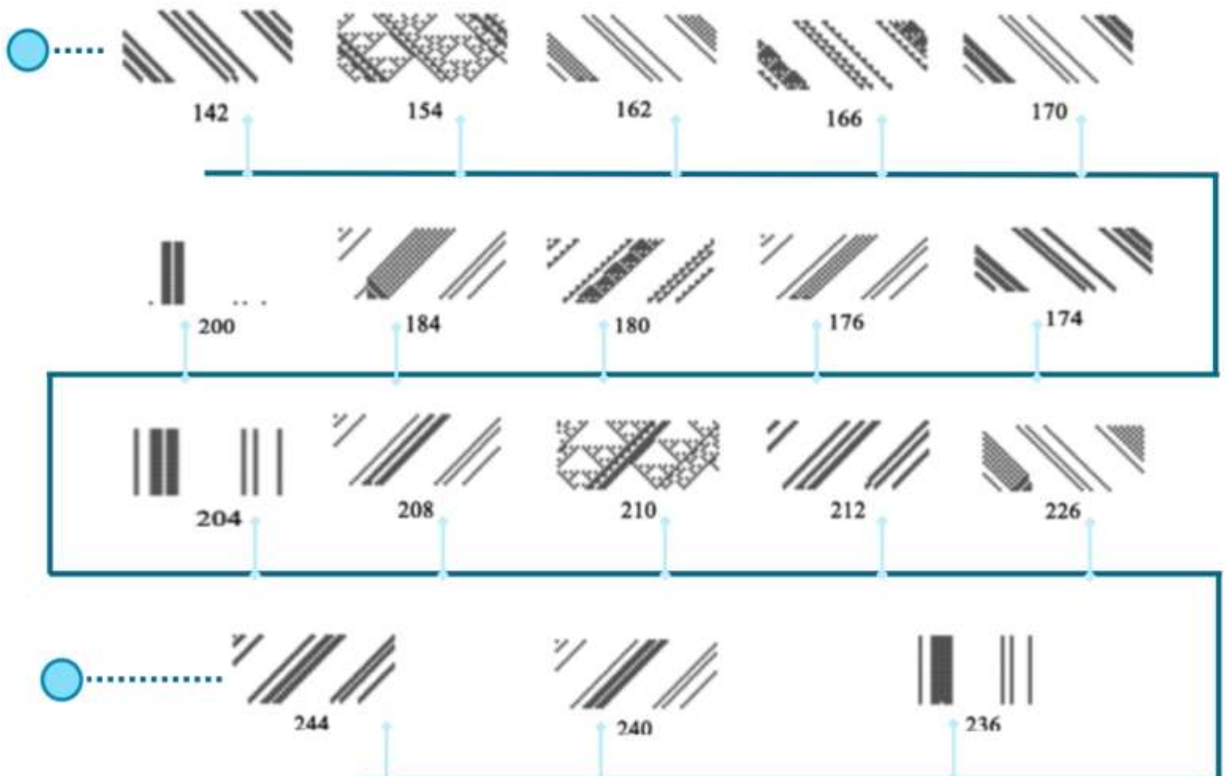
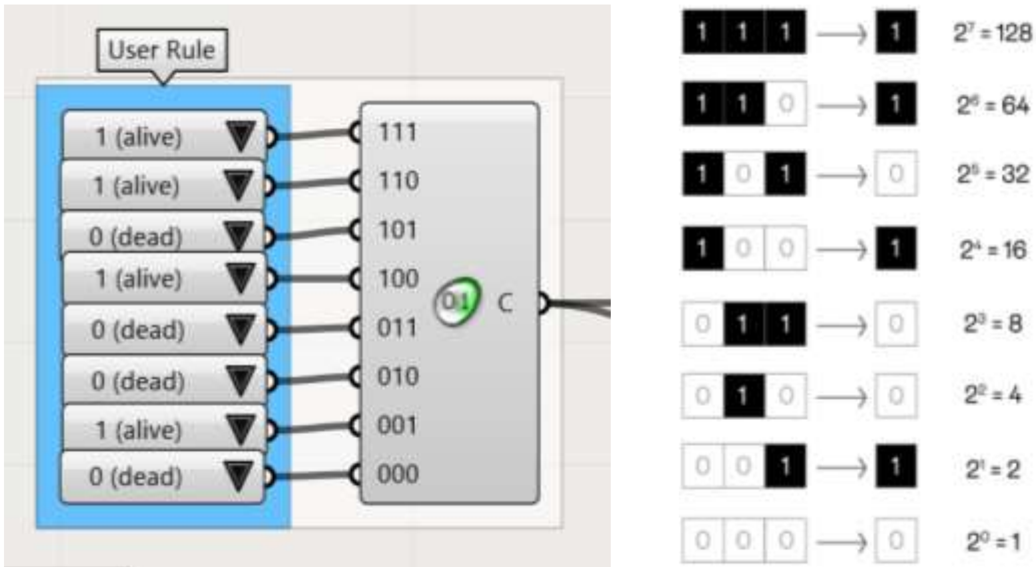


Fig. 10 Replacing Black Cells with Green Façade (Source: [4] and Modified by Researchers).

- Rule 210 Logic

Cellular Automata consists of a grid of cells arranged next to each other in an array-like structure. The value of each cell is determined by the corresponding previous value and the two cells next to them in the previous time step. These three values have eight configurations of zeros, contributing to 256 different sets of rules. Rule 0 starts when all the cells are referenced as dead, and Rule 256 is when all the cells are referenced to be alive. Each rule presents unique cellular automata patterns used in different applications. The chosen rule of 210 holds an interesting set of rules, as shown in Figures 11 (a) and 11 (b).



(a) (b)

Fig. 11 (a) and 11 (b) shows Rule 210 Source: Researchers.

4.4 Greyness Function

The balance between the white and black cells determines the overall density of the façade; this is called Greyness Function [6]. The Greyness Function is one of the most critical criteria to judge which Cellular Automata rule is better for façade utilization. The balance between the zeros and the ones should be found to search for a visually balanced façade and an environmentally integrated one. In order to maintain the visual connection between the interior and the exterior and enhance the interior environment by achieving the optimum daylight distribution, the ratio between the black and white cells should be achieved.

As a selection criterion, the balance between the living green wall modules and the glass modules should be available for picking the final proposal for Cellular Automata Façade. This point is because the designed façade should achieve three main qualities: functional quality, aesthetic quality, and environmental quality. These qualities should be represented by the outdoor users viewing the office building and the interior user.

To conclude, various aspects should be taken into consideration when selecting the green Cellular Automata façade. The functionality of the façade, where there is a balance between the visual connection between the users in the space and the outside environment, is one of the most important aspects to consider as well as having a daylight-optimized design that meets the requirements of optimum daylight factor in interior spaces. The final aesthetics of the façade is essential for the users pacing by the space in the exterior environment. The next part of the research discusses the different iterations of the design, the criteria of evaluation, and the chosen design.

4.5 Experimentation

Using the Morphcode plugin in grasshopper, different iterations were produced and tested according to the criteria concluded from the examples analyzed. The final façade differs according to the first line conditions, and points were picked in an organized manner to create a homogeneous final look, as shown in figures 12 and 13.


(12)

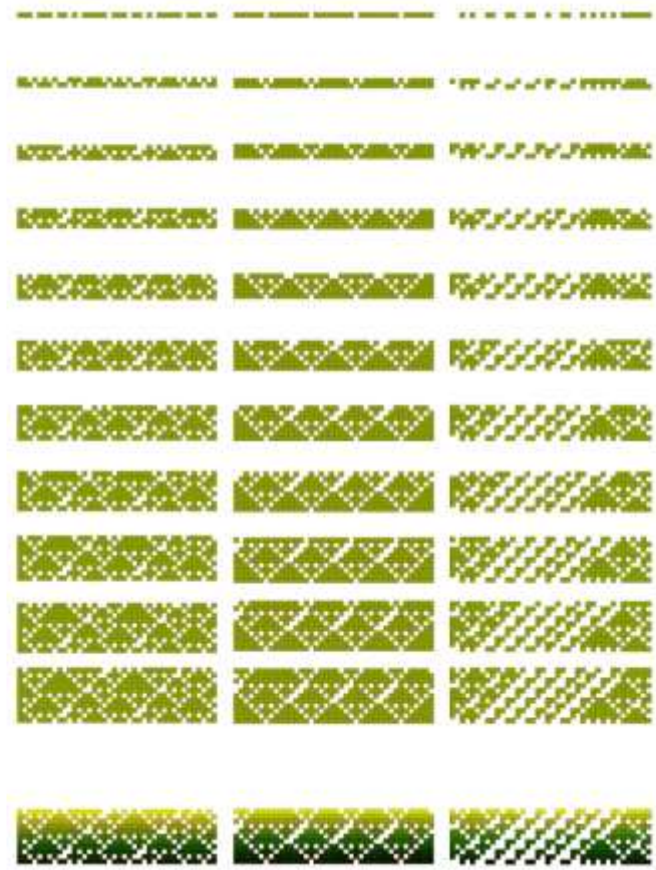

(13)

Fig. 12 and Fig.13 Iterations based on starting points Source: Researchers.

5.RESULTS & DISCUSSION

After several iterations and experimentation, the proposed design is chosen based on the previously acquired criteria. The Greyness Function of the design is balanced for the main aim of having a continuous visual aspect between the interior and the exterior and having a comfortable, environmentally friendly interior environment. As shown in Figure 14 and Figure 15, the chosen design results from an algorithm-based Cellular Automata pattern; therefore, it will not have the same errors as previous examples analyzed. Several renders have been produced to visualize this research paper's idea.

The chosen design is proof of the concept that cellular automata can be integrated with vertical green to create a balanced system of visual continuation, functionality, and environmental aspects. The design should be further analyzed using energy simulation software to calculate the environmental factor of the interior space. The results then should be compared with the design without having vertical green elements to present the optimal design scenario that serves the three main cores of the design: the aesthetic, the functional, and the environmental. The results could be only achieved if it’s applied on a south oriented façade that represent the same qualities similar to the Mediterranean climate of Alexandria, Egypt.

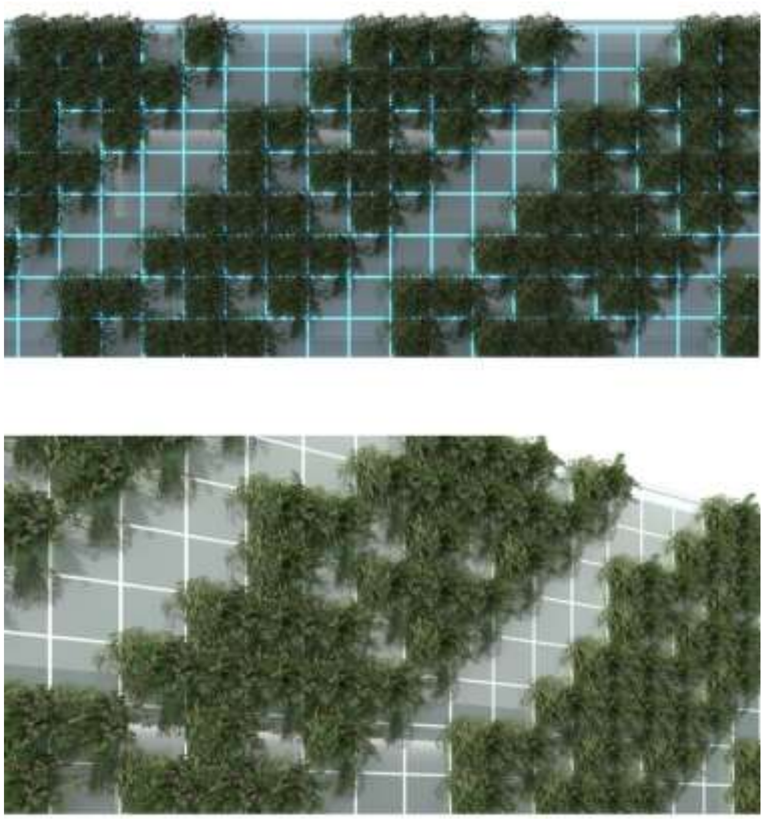


Fig. 14 Proposed design renders details Source: Researchers.

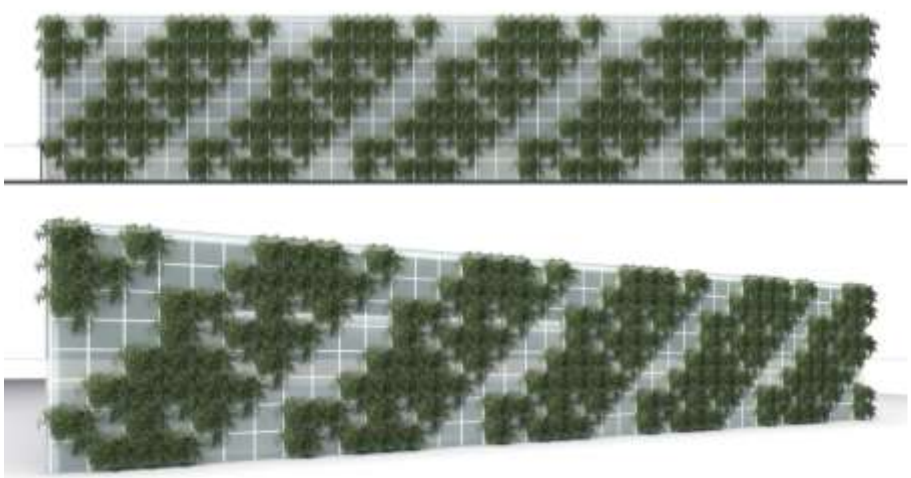


Fig. 15 Proposed design renders elevation view Source: Researchers.

6.CONCLUSIONS & RECOMMENDATIONS

The shift in design towards computational methods is a way of linking technological advancements with the architectural realm. These new methodologies should be integrated with the design to achieve interesting results. This research paper is an experiment with the concept of integrating Cellular Automata with a green façade. Exploring these two systems simultaneously helps the research to integrate these two systems together correctly. The self-similar Cellular Automata pattern creates a system that can be adapted for multiple purposes. Integrating Green elements in this design further contributes to the overall environmental design strategy.

Further research can be dedicated to the environmental analysis of the proposed design and optimizing the Cellular Automata patterns accordingly. In addition to further empirical work is required to extend the applicability to other parts of Mediterranean cities in Egypt.

The chosen design is proof of the concept of integration between cellular automata and vertical green that would provide architects and policy makers with methodology to facilitate building performance simulation and façade design. Therefore, the outcome of the research aims to provide architects, interior designers, and practitioners with an optimized dataset for façade design to use and apply in south oriented facades.

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تطبيق نظام تظليل متكامل مع الخلايا التلقائية " واجهة جنوبية – دراسة حالة"

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الملخص

مع الاستعاضة الواضحة للبيئة الطبيعية بالبيئة التي هي من صنع الانسان وزيادة معدل اكتساب الحرارة من الشمس في مناخ منطقة البحر الابيض المتوسط سلط الضوء علي البحث في إمكانيات استخدام واجهات موفرة للطاقة في المباني. في هذا البحث، تم دراسة خلايا تلقائية (**Cellular Automata**) كاستراتيجية لتعديل الواجهات القائمة بنظم تظليل ثنائية الخلية محسنة من خلال دمج الاسطح الخضراء للحيز المكتبي ذي الوجهة الجنوبية في مناخ الإسكندرية المتوسطي. يساهم البحث في تحسين أداء الإضاءة النهارية وخلق بيئة داخلية أكثر متعة. االهدف الرئيسي لهذا البحث هو محاولة استخدام أسلوب التصميم التنمي لتطبيق غشاء على واجهات موجودة مع دمج عناصر خضراء في الاتجاه العمودي . يحلل االبحث محاكاة ضوء النهار للحيز المدروس باستخدام برامج لتحديد أفضل المواقع لاستخدام السطح الأخضر. ثم يتم تقييم أنماط مختلفة من العمليات الحاسوبية الخلوية لتحديد القواعد الممكنة اللازمة لتطبيق أنظمة التظليل المتكاملة ثنائية الخلية محسنة من خلال دمج الاسطح الخضراء. ثم يتم تحليل أداء الواجهة المصممة من خلال المعايير المقترحة. في نهاية البحث يتم عمل تحليل مقارن بين النتائج لبيان الأثر الإيجابي المترتب على التعديل. يمكن أن تعمل هذه التقنية كأداة يستخدمها المصممون لتحقيق جودة داخلية أفضل وتحسين الخصائص الجمالية للمساحة الداخلية.

الكلمات الدالة:

خلايا تلقائية ، الاسطح الخضراء، كسريات، حدائق راسية، واجهة خضراء، الاستدامة، النظام التوليدي.

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