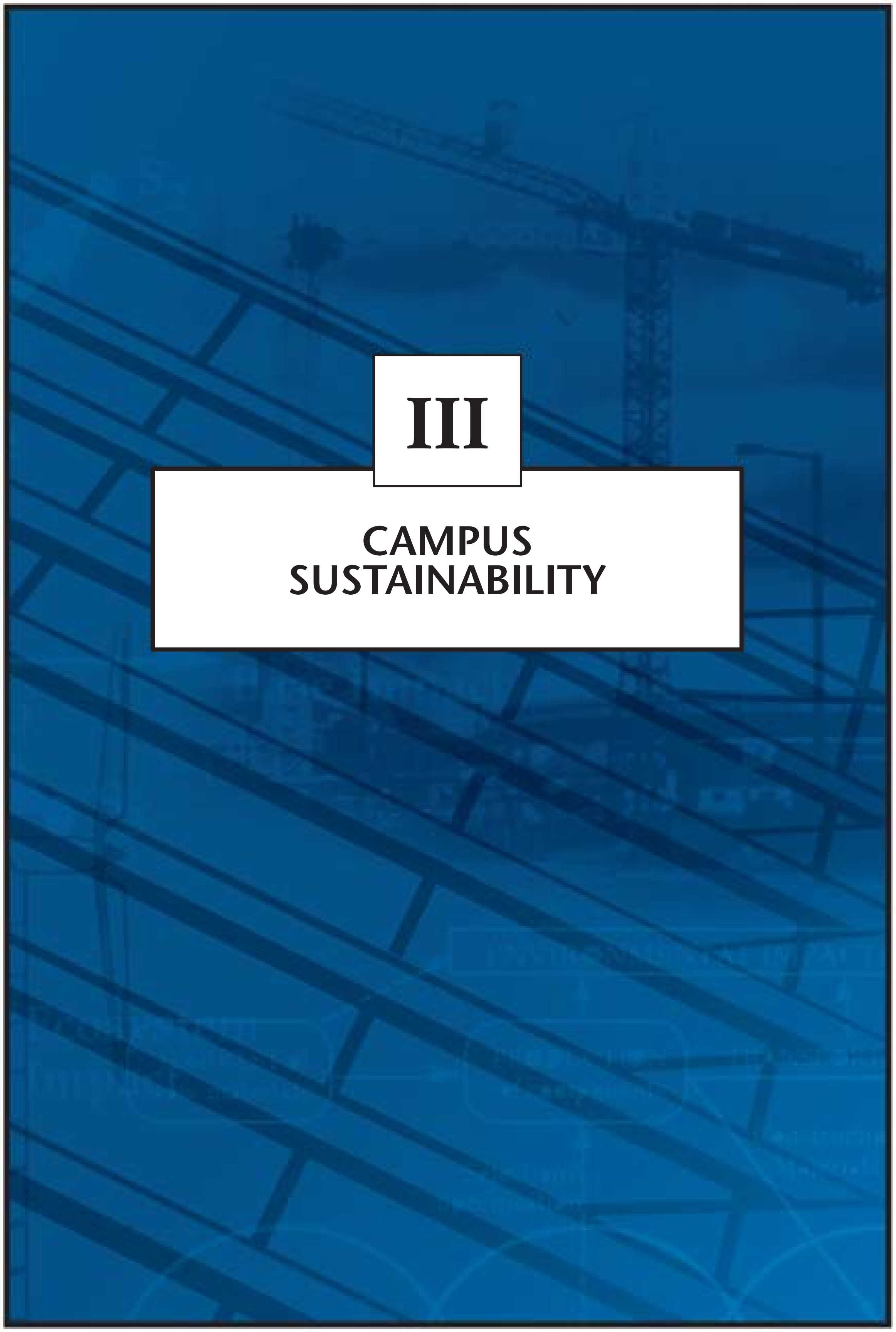

III

CAMPUS SUSTAINABILITY

ENVIRONMENTALLY RESPONSIVE KINETIC FAÇADE FOR EDUCATIONAL BUILDINGS

Flora Fakourian,[1] Maziar Asefi[2]

ABSTRACT

The sustainable development of educational buildings has become an increasingly important goal for university campuses. This research develops a proposal for a kinetic façade employing mechanical moveable components for an educational building. Due to the pedagogically different needs of courses taught in educational spaces, it is desirable to design spaces that are able to meet changing functional and aesthetic requirements. The transformation of an exterior curtain wall is performed by means of movement and twisting of its components in order to regulate the temperature and sun penetration for each class during the course of a day. This paper proposes a curtain wall system for educational buildings. The transformation mechanism and the details of the wall's components, along with the construction plans and material used are presented. It is argued that the proposed design can respond properly to the architectural principles of educational buildings in terms of form and function, while also respecting the varying needs of users and environmental sustainability.

KEYWORDS

educational building developments, curtain wall, energy efficiency, mechanical instruments, adaptability

INTRODUCTION

Kinetic systems have a long tradition in ancient and historic architecture. Doors and window shutters are the simplest and the most common examples of moveable components used in ancient buildings. Since then, these systems have been developing until now robotic and intelligent systems are used (Ramzya, et al., 2011, 170). A building facade is one of the most well-known intelligent systems that could increase internal comfort and at the same time decrease energy consumption for the building it encompasses (2). It is in the field of educational buildings that some of the most innovative daylight solutions have been developed to meet educational buildings' increased emphasis on sustainable measures that offer energy savings while being attentive to occupant comfort. There has been a trend in educational building design to use more glass in façades to provide enough natural light into learning spaces. However, economic justification of the use of these transparent skins are very important in terms of sustainability and

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energy saving. In order to mitigate the negative impact of using wide windows, kinetic façade systems are used that can intelligently control the use of natural lighting and natural ventilation.

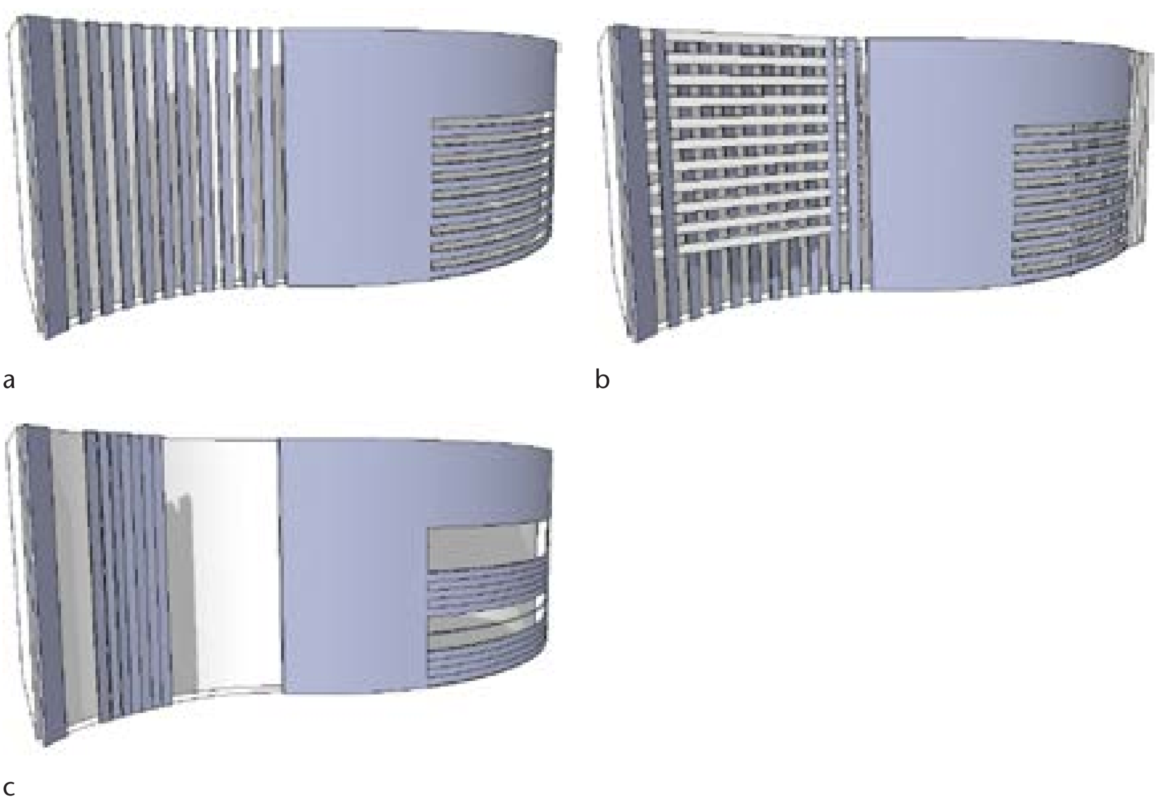
EVALUATION OF EDUCATIONAL BUILDING FACADES

In this section, the existing facades of some important educational buildings will be evaluated according to the compatibility with their building program and function. A general review shows that most of the educational buildings use double skin façade with either fixed (fig. 1,[a]), adjustable (fig. 1,[b]) or moveable panels (fig. 1,[c]) in order to primarily control the amount of daylight that enters into the building. Existing facades of educational buildings are reviewed in three main categories of fixed, moveable and adjustable will evaluate how the choice of façade system, mechanism and material may respond to the design requirements in terms of function, sustainability issues and aesthetics considerations (fig. 1).

Facade with fixed panels

In this group, façade components are fixed and do not alter in response to environmental conditions. They can be vertical, horizontal or a combination of both modes to provide proper natural light for spaces in different directions. The Royal Veterinary College's new Teaching and Research Centre (TaRC) (fig. 2), situated at the heart of its Hawks Head Campus, benefits from natural ventilation and a stylish Solar Shading solution from Levolux. The TaRC building features Western Red Cedar cladding and generous glazing, including two roof lights, which

FIGURE 1. [a] fixed panels, [b] adjustable panels, [c] movable panels.



allow daylight to illuminate the building. To ensure optimum internal conditions are maintained within the building and its roof plant room, Levolux was invited to develop a solution combining its successful Infiniti Fin system, along with its Ventilation and Screening Louvers. Heavily serviced laboratories, situated along the south-facing elevation, are warmed naturally by the sun, double-height glazing, which also gives them a light, airy feel. While this is highly desirable during the winter, solar heat gain can become excessive in the summer without solar control. Levolux's Infiniti Fin system was chosen to provide effective solar control. Eleven horizontal, aero foil-shaped Fins are fixed at 45 degrees to absorb and reflect a proportion of the sun's rays before they enter the laboratories, thereby limiting solar heat gain in the summer. With its unique design, the Infiniti Fin system features integral stainless steel fixings, allowing supports to be concealed within the Fins themselves. In contrast with traditional bird mouth/beak type fixings, this not only creates a neater, sleeker aesthetic, but also gives the Fins greater structural integrity, so they remain stable under the most extreme weather conditions.

Façade with adjustable panels

The components of this type of facade can be adjusted by means of twisting or rotation either mechanically or electrically in order to respond to required situations. For example, the new learning centre of excellence, Kolding Campus (fig. 3), will house courses in communications, design, culture and languages at the University of Southern Denmark. The shape and facades of the building create a powerful dialogue between the inner life of the building and the outside observer. The facade is an integrated part of the building and together they create a unique and varying expression. Inside in the five floor high atrium, the displaced position of the staircases and access balconies creates a special dynamics where the triangular shape repeats its pattern in a continuous variety of positions up through the different floors. The activities open up towards the town so that the campus plaza and the interior study universe become one interconnected urban space with a green park at the back and a common recreational town plaza at the front.

The complex and extensive program for the project into podium and superstructures allowed the creation of an extended public domain of lawns, terraces and plazas at the podium

FIGURE 2. The Royal Veterinary College's new Teaching and Research Centre (TaRC). (11: http://www.rvc.ac.uk)

a

b

FIGURE 3. University of Southern Denmark, Kolding Campus. (12: www.archilovers.com)

level, or Eastern Avenue level, the primary public artery of the campus (fig. 4). Within this solid podium are the library and teaching spaces accessed from the terraces and lighted from above. Suspended above the podium are a series of superstructures that split and splinter the remaining program into fragments that coalesce at moments of definition of the public domain. These splintered forms are frozen or locked in position by three glass and metal elements and a spatial urban shaft. A cubic glass atrium locks the fragments of the teaching form into spatial and urban alignment at the moment of primary vertical circulation.

Movable panels

Kinetic façade is an active architecture that is responsive to environmental conditions. In order to satisfy user changing needs these systems are usually made of two parts: a solid structure sequesters and a movable textile infrastructure. Movable panels are the light-emitting curtains that create spatial divisions and personal micro-climates. Kinetic louvers also move in three dimensions to screen sunlight from any angle. As an example, the components of this type of facade can be adjusted by means of twisting or rotation, either mechanically or electrically, in order to respond to required situations. The Industrial Technology Research Institute (ITRI) is a public research institute in Taiwan. Different degrees of lighting were required according to the nature of research at each laboratory in this research complex. It was not possible to adjust lighting by changing the shape or size of each opening and such solutions would also result

FIGURE 4. Faculty of Law, Library and Teaching Complex, University of Sydney. (10: http:// www. buildings).

a

b

c

in a disorganized exterior appearance. The design solution was to provide soft, veil-like facade layers composed of 4000 fins, which are offset from curtain walls, creating the double-skin building envelope. The double-skin composition makes it possible to hide maintenance spaces in between, while providing flexibility for the future addition of pipes and ducts without affecting the landmark appearance of the building. The interior light environment is controlled by adjusting densities and angles of the fins, while the fin system gives the integrated appearance to the facility (fig. 5).

Smart panels

The concept of the smart facade uses weather forecasts, predicted occupant behavior (based on past experiences and by means of an integrated approach of artificial intelligence) and current requirements and boundary conditions to adopt physical properties that lead to an energetically optimized performance as well as comfort for users. Back in 2011, the chemical company Alcoa unveiled a technology that could clean the air around it. The material contained titanium

FIGURE 5. Industrial Technology Research Institute (ITRI). (13: http://www.archello.com)

a

b

c

dioxide, which effectively "scrubbed" the air of toxins by releasing spongy free radicals that could eliminate pollutants. A New Mexico City hospital, the Torre de Especialidades, uses a technology based on the same process: As air filters around the sponge-shaped structures, UV-light-activated free radicals destroy any existing pollutants, leaving the air cleaner for the patients inside. According to Fast Company, even the shape of the sun screen is significant: It creates turbulence and slows down air flow around the building, while scattering the UV light needed to activate the chemical reaction. Another example is An Energy-Producing Algae Façade that is tinted by millions of microscopic algae plants that are being fed nutrients and oxygen to spur biomass production. Facilitated by direct sunlight, the speedily-growing little cells end up heating the water, and that heat is harvested by the system and stored for use in the building.

Hybrid panels

A hybrid system exhibits both smart components and a kinetic structure—a system that can move and at the same time, with use of a smart material, can control environmental changes. A hybrid system has the benefit of encompassing a larger class of systems within its structure, allowing for more flexibility in modeling an exterior envelope. Hybrid systems have been used to model several buildings, including Sean Godsell Architects' RMIT's Design School, which is sheathed in thousands of small, sandblasted glass circles—each affixed to a central rod. Based on humidity and temperature inside the building, these rods pivot automatically to facilitate (or block) the flow of air through the facade. Another example is a new model for low-carbon

FIGURE 6. [a, b] Mexico City hospital, the Torre de Especialidades Hybrid panels. [c] Energy-Producing Algae Façade which tinted by millions of microscopic algae plants. (14: http://www.archello.com)

a

b

c

urban housing. It is called the Soft House and won first prize in an invited design competition for the IBA. The Soft House, an innovative work/live row housing project, is now demonstrating novel concepts in energy and architecture at the IBA in Hamburg, Germany. The four housing units include a responsive energy-harvesting textile facade and movable light-emitting interior curtains that enable occupants to reconfigure their domestic space, creating a flexible new model for carbon-sequestering architecture. Each unit has a terrace space, a PV canopy, and a vertical convection atrium layer that circulates air, brings daylight into the ground floor, and creates vertical views of the sky. The four housing units share an energy-harvesting facade with integrated flexible solar cells. As shown in the four small diagrams at the right (fig. 7), the individual strips of the facade change position to track the daily and seasonal movement of the sun. Top (winter): The facade is fully raised to capture lower winter sunlight, and many strips are twisted to let in sunshine. Second down (autumn): Some strips are raised and twisted. Third down (summer): The facade is lowered to capture the higher summer sun, and the strips are fully closed to provide shade. Bottom: The facade retracts flat against the roof during a storm.

FIGURE 7. [a, b] Sean Godsell Architects'sheathed RMIT's design school. [c, d] A pop-apart drawing of the Soft House, with the PV- and LED-embedded textile installations highlighted. (15: http://www.archdaily.com)

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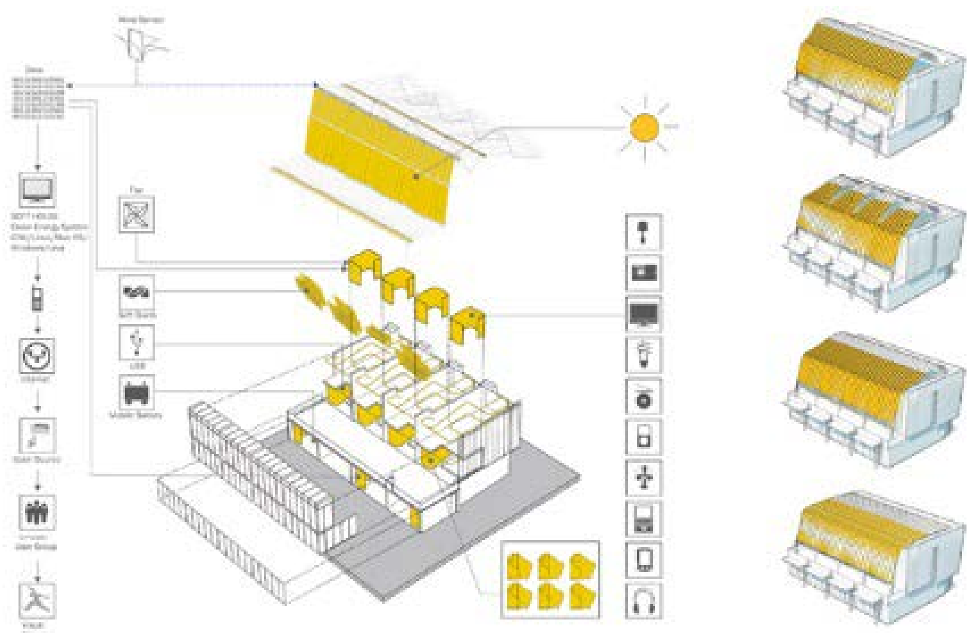

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TABLE 1. Advantages and disadvantages of changeable facades.

	Advantage	Disadvantage
Fixed panels	Sunlight control—Usage in different climate—Reduce energy consumption—Energy efficiency-Thermal insulation—Slower air flow near the façade	Lack of flexibility—Limited prospects due to the fixed supporting structure—Uniform views—Reduction in usable space—May negatively affect the view.
Adjustable panels	Sunlight controller—passive or active solar energy—Cope with different climates—Reducing energy consumption energy efficiency—Thermal insulation, variable envelope	Limited prospects due to the supporting structure—Reduction in usable space—Costly construction and maintenance. May negatively affect the view
movable panels	Sunlight controller—cope with different climates in different direction on building—variable views—Thermal insulation—cleaning air flow from pollution, thermal sensitive due to energy control	Costly construction and maintenance—Design complexity
smart panels	sunlight collector—passive solar energy—Reducing energy consumption—changeable façade—transformable skins—smart control of energy	Costly construction and maintenance—Design complexity—Use of expensive materials
Hybrid panels	sunlight collector—passive solar energy—changeable façade—transformable skins—smart control of energy—full control over sunlight and energy consumption—Separate control over supporting system and material	Costly construction and maintenance—Design complexity—Use of expensive materials

EVALUATION OF EDUCATIONAL BUILDINGS' FACADES

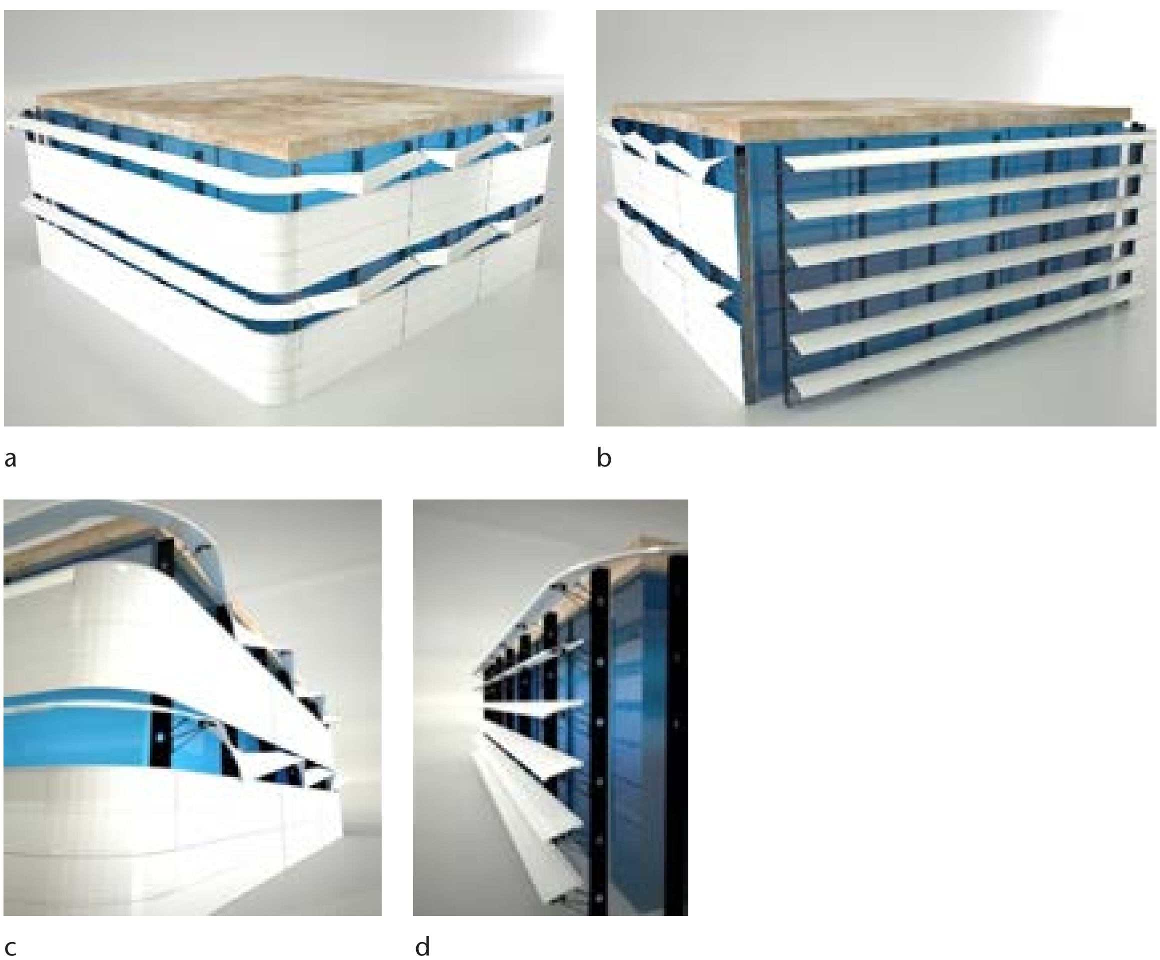
Evaluation of educational buildings with different facade systems shows that there is a developing trend toward the use of façade systems that could interact with environmental changes and building functions. Moveable and adjustable façade elements can best meet designer and end user's requirements and can provide more sustainable architectural solutions. Moreover, due to different functional requirements of educational spaces derived from the different courses and programs taught in these buildings, kinetic and adaptive facades seem to be one of the best options for educational building design. A brief comparison among the different façade systems used in educational buildings is summarized in the following table:

The evaluation shows that to gain the best quality in educational spaces, the design should have the ability to adapt to environmental changes in terms of light, heat, while at the same time providing a comfortable environment for students. Building skins for educational structures play an important role in promoting teaching and learning processes. One solution is the use of moveable components that are able to be stored and transformed in different directions in order to obtain maximum light and quickly adapt to changing climate. Storing whole units on one side of an exterior envelope gives building skins more flexibility and can reduce the negative effect of fixed shading systems. In proper weather conditions, when shavers are not required, folding moveable panels in a designated area can provide the skin with a clear, non-blocked view that is not possible when a fixed shading system is used.

PROPOSED KINETIC SYSTEM

Due to the differences between the needs of courses taught in educational spaces, it is desirable to design spaces able to meet changing functional and aesthetic requirements. By involving real movement, and by means of kinetic façade, it is possible to interactively respond to the requirements of educational spaces. However, care needs to be taken in order to not interfere with the function of the educational environment. Noise pollution related to movement and the high cost of transformable components are the main issues are the main reasons why kinetic facades have not been used extensively in educational buildings. The proposed movable façade uses cost effective detailing and components (fig. 8) that can meet customer's taste by responding to the functional and environmental requirements. Moreover, the exterior skin is able to open and close in order to regulate the temperature and sun penetration in each class during the course of a day. The façade embedded with photovoltaic cells uses a simple mechanism and can be

FIGURE 8. Hypo surface three-dimensional model, different position of lamellas on each side of the building.



controlled manually or electrically. The aluminum plates and telescopic bars with the rubber wheels can also decrease the noise pollution associated with movement.

The proposed design consists of two main parts: A shell surface (fig. 9 [a]) and a kinetic driving system (fig. 9 [b]). The shell surface consists of a series of panels that move up and down either together or separately (fig. 9), so that their movement allows the building skin to be exposed to different sunlight directions in order to meet users' comfort conditions. These shell surfaces are named lamellas in this paper. Each lamella is 2 meters in length and 50 cm in width and consists of 16 sections of 12x50 cm (fig. 9, [b]) connected to the main frame by means of two holding parts in both ends (fig. 9, [b] and fig. 11). The sections of each lamella are attached together by four main elements: a horizontal supporting member (the red section shows in (fig. 8 [b, 1]), a cable (Nitinol can be considered) (fig. 8 [b, 3]), a rigid tubular rod (fig. 9 [b]) and two side supporting elements (fig. 8 [b, 2]). The horizontal supporting member is connected to the lamella's sections by means of a hollow tubular rod attached to it and the rigid metal bar holding the sections together (fig. 9 [b]). Each lamella's section is connected to the rigid bar of the horizontal supporting member through three metal rings that make the movement of the section possible (fig. 9 [a, b]).

There are also two telescopic bars attached to the side supporting elements that makes the movement of each lamella possible. (fig. 10 [1, 2]) When it is going to be closed, the big wheel (fig. 10 [c]) rolls on the (fig. 10 [2]) bar and with the rotation of wheels the whole lamella could be moved up and down.

FIGURE 9. [a] sections which make the shell surfaces, [b] kinetic driving system's components, [c] shell surface rotation on façade, [d] an elevation of a shell surface.

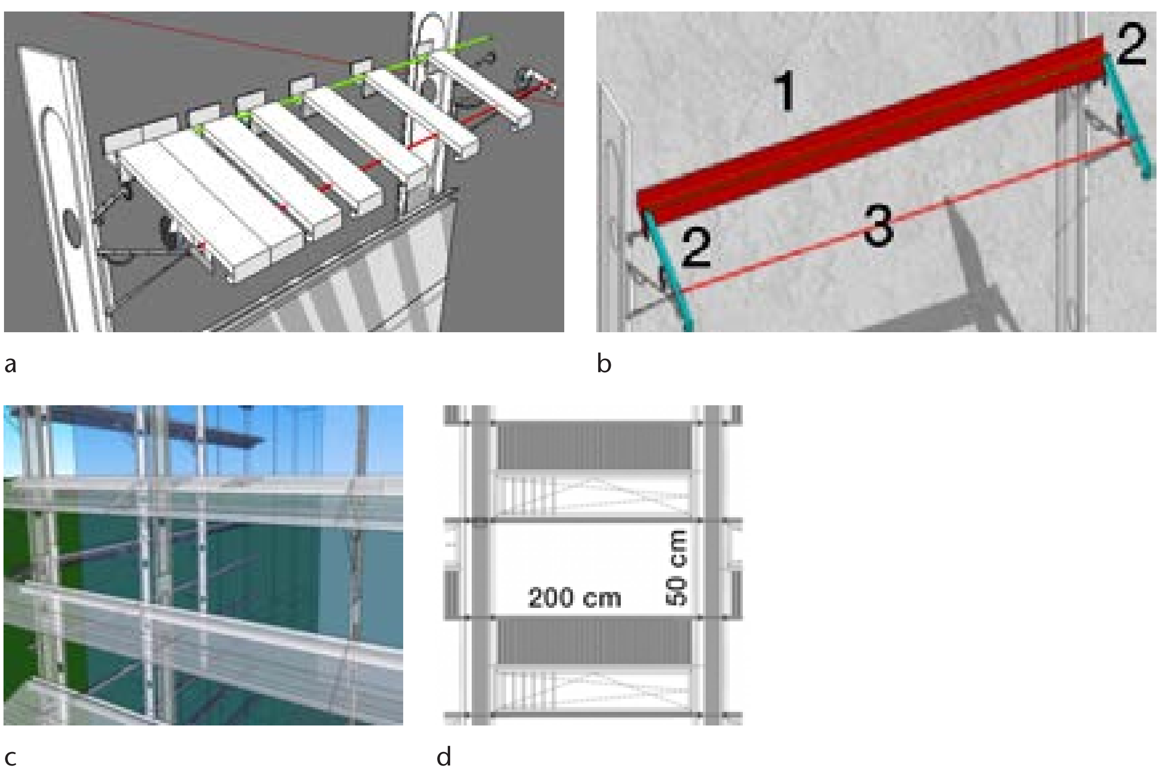
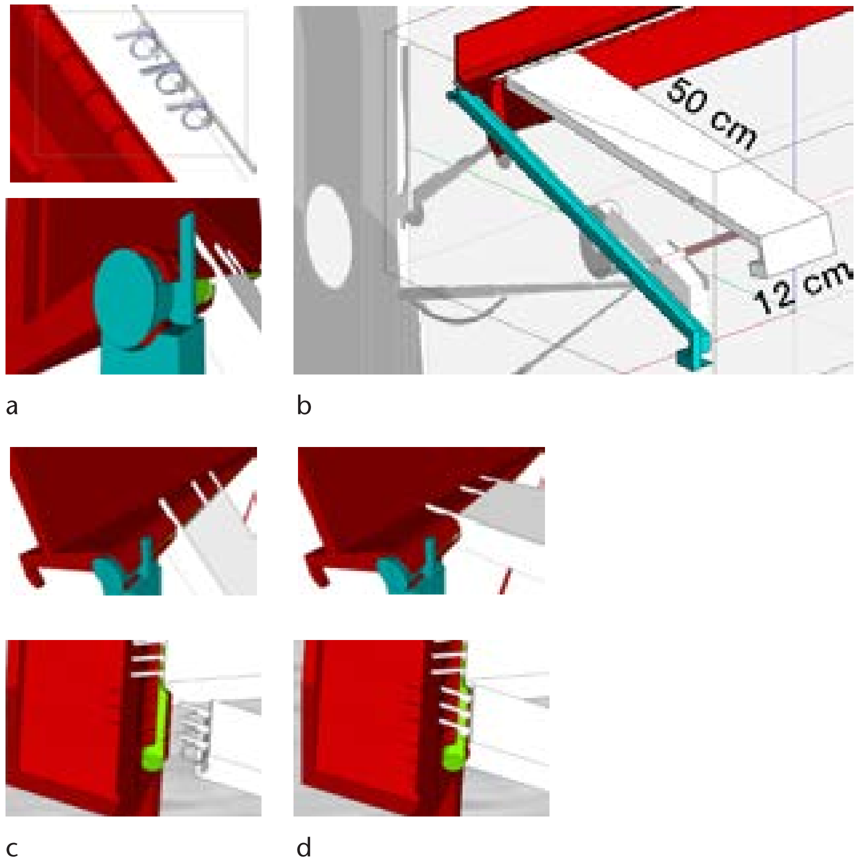


FIGURE 10. [a] three tubular rings, [b] 12 cm sub-section attached to horizontal holding member and the end bar, [c, d] detail of the end bar.

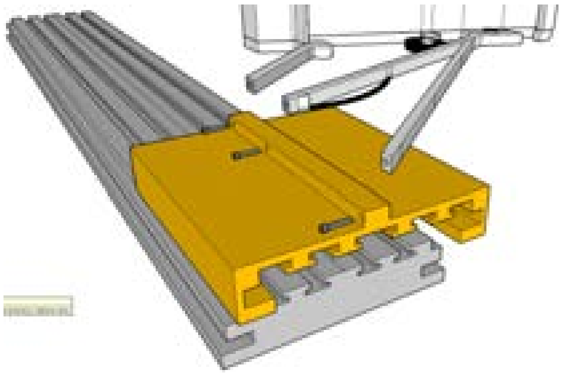


Each lamella can also move up and down individually through the rails connected to the main structural system of the façade as seen in figure 10. Figure 12 shows how each lamella can be transformed when the telescopic bars are operated. This controls the amount of light coming through and also allows the façade shape to be adjusted as required by users. Moreover, the movement of the lamellas can create an animated pattern on the façade.

The other interesting feature of this façade is the ability of the lamellas to be stacked on top of each other and be stored on top of the facade (fig. 12). In weather conditions when there is no need for shading devices, the lamellas can be closed and packed in order to provide an unobstructed view to outside.

These moveable panels can be employed in different directions in various buildings and can effectively moderate the light and heat penetration according to the users' requirements and according to environmental changes. For example, on the north side, the panels can angle up to reflect the ambient light and to brighten the inside of the building (fig. 13 [b]). On the south side, they rotate as much as required to filter the direct sunlight and provide a comfortable environment (fig. 12). For east and west directions, they can completely or partially be closed during some hours of a day in order to prevent unpleasant sunlight coming into the building (fig. 13 [a]).

FIGURE 11. [a] moving mechanism on the side rail, [b] kinetic detail, [c] Structure and system joint, [d] System of change.



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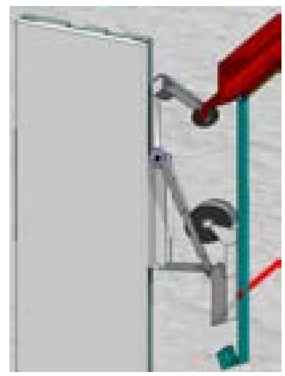

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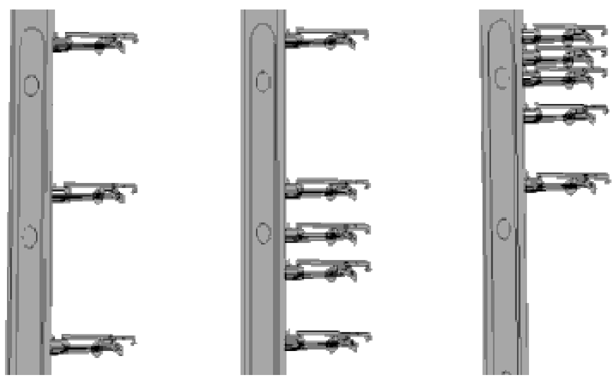

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DEVELOPMENT OF KINETIC FAÇADE SYSTEM

The proposed design can be further developed so that it can be moved and transformed in different directions and orientations. The moveable panel can be moved in both vertical and horizontal directions, and it is possible to transform them into non-regular shapes according to building requirements by adding hinges and pivots in the panels and with the employment of flexible materials as shown in figures 14 and 15.

This proposed system is a result of a collaboration between the fields of architecture, technology and industrial design. In order to design a sustainable facade with a high degree of intelligence, the system should be equipped with electrical sensor-operated components. The sustainable concept of the façade is able to prevent the unwanted heating, cooling and lighting that are usually the weaknesses of building skins mainly covered in glass. The façade could be changeable and able to open or close itself according to the data received from sensors. It could be made in such a way that it can close itself when the daylight or the view is not required. In this scenario façade architecture and data-visualization are linked together in order to make an energy-efficient and environmentally sustainable building. The transparent hybrid panels made from bio-composite and recyclable material systems can effectively provide more sustainable solutions to glazing systems.

FIGURE 12. [a] side rotation, [b] geometry of movement by divided sections, [c, d] elastic deformations by small parts that stick together with a wire. A three dimensional view of the stacked and the vertical supporting components.

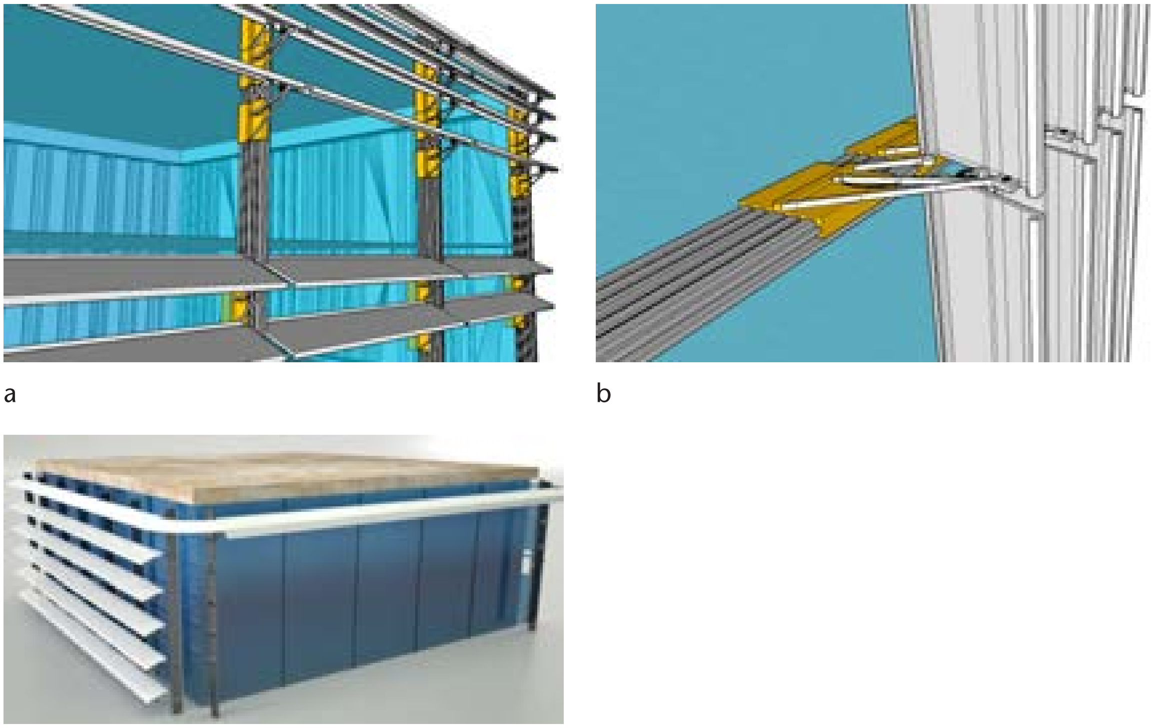

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FIGURE 13. A: [a] shading structure, [b, d] telescopic slat, [c] wire, [e] lamella, [f] linear roller, [g] shape memory metal wire, [h] roller; B: patterns of changing components.

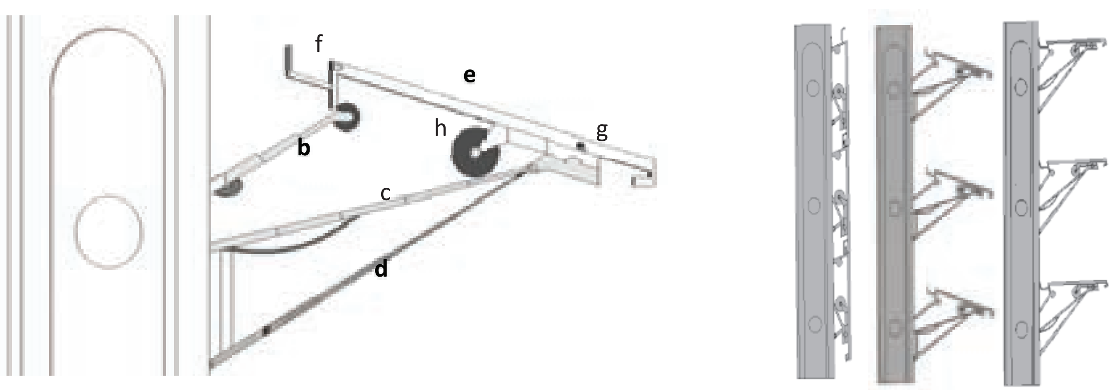

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FIGURE 14. The attachments of the panel section to the kinetic system. Moving lamellas on the side rail, plate detail.

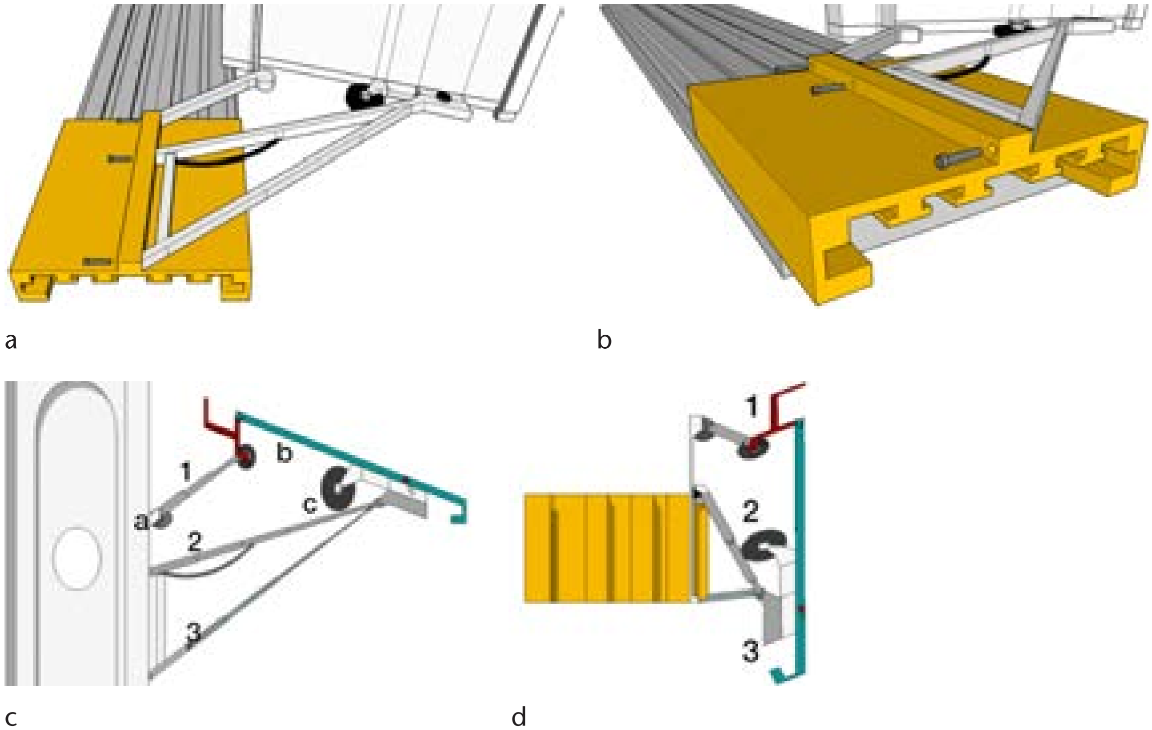


FIGURE 15. The development of system came by the possibility of the orientation of the installation of exterior curtain walls.

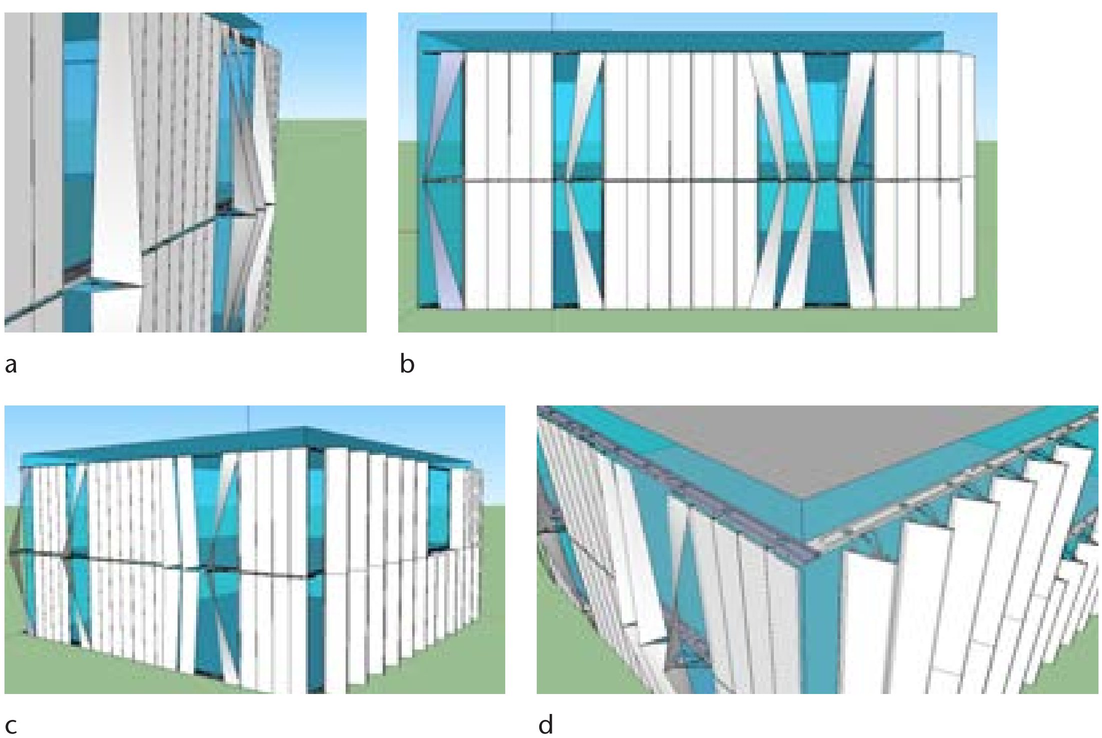
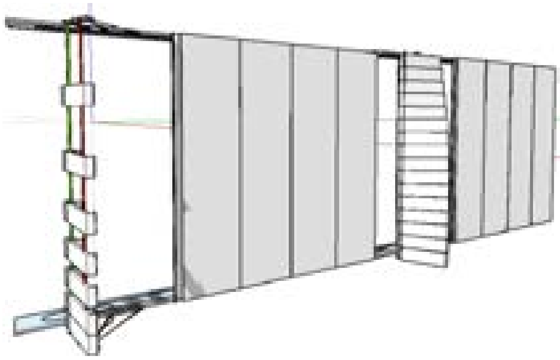


FIGURE 16. The details of development of system installation of exterior curtain walls.



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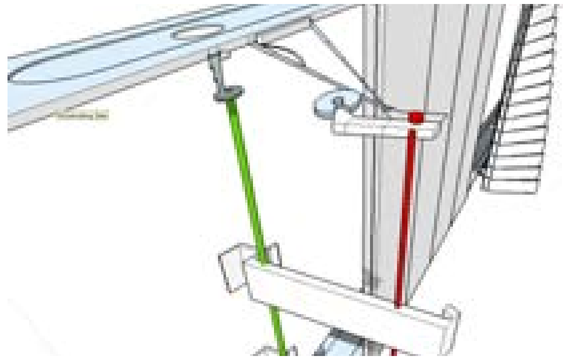

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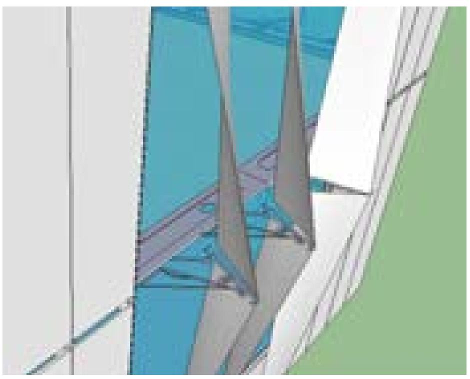

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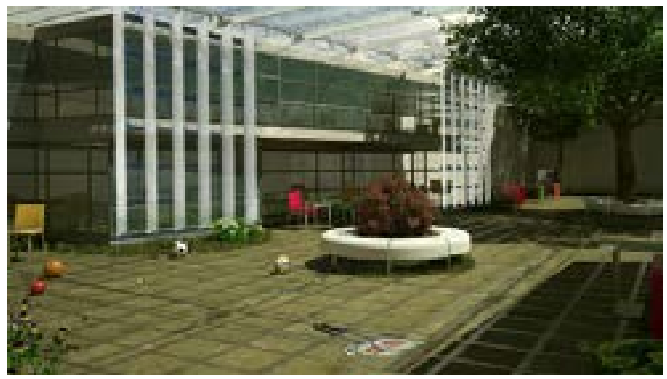

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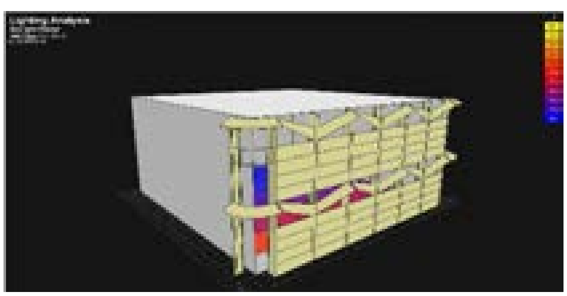
FIGURE 17. Natural light provided by different shapes of shading, Ecotec analysis.



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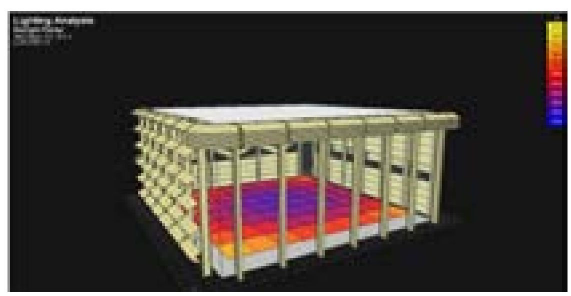

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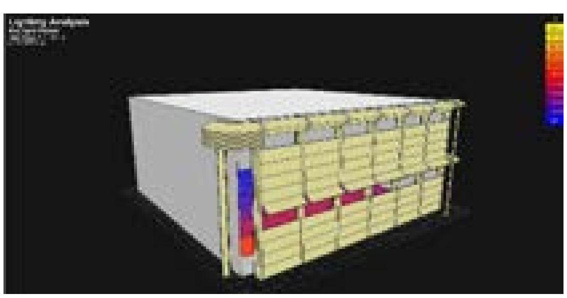

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Ventilation Louvers and Screening Louvers are combined to enhance the building's external envelope, by reducing solar heat gain, encouraging natural ventilation and creating a pleasant aesthetic quality. In the large vertical spaces, air will be infused through the floor, to reduce the amount of conditioned volume. During daytime the kinetic lamellas are used to control solar input; they will be operated by energy gained through the solar panels on the roof.

MATERIAL PROPOSAL

In this system, the use of solar energy and organic material such as "Nitinol" can be considered. Nitinol is a shape memory material (the shape memory effect means that when an alloy is deformed at low temperatures and subsequently heated, it reverts to its original shape) [3]. Nitinol wire is used in order to attach the small part of lamellas and perform according to changes in the temperature. When it is heated, the wire stretches itself and makes the 12 cm lamella sections move (Fig. 19. [a]). The lamellas are made of glass fiber reinforced polymers

FIGURE 18. [a] Deformation of wire makes the lamella move, closed, semi opened, open; [b] Red line in the lamella can be metal wire; [c] Horizontal units of kinetic façade on educational building inner yard.

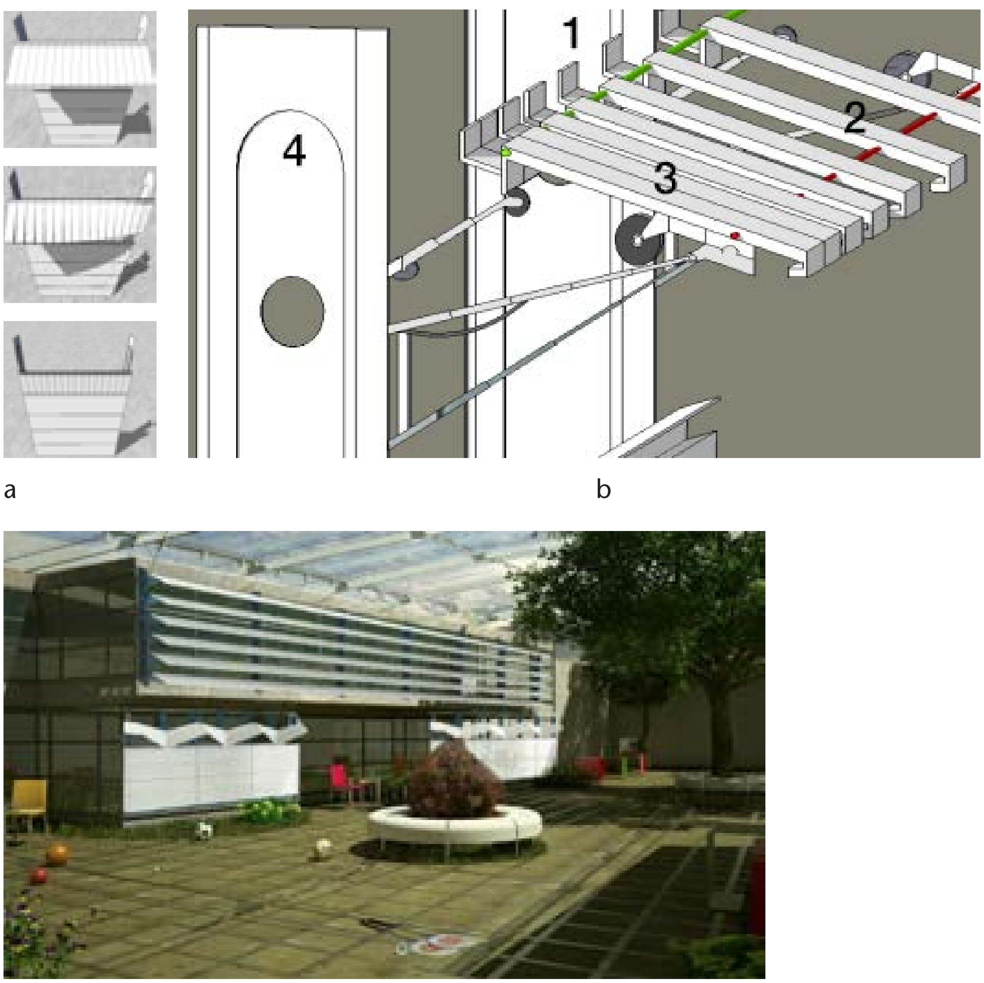

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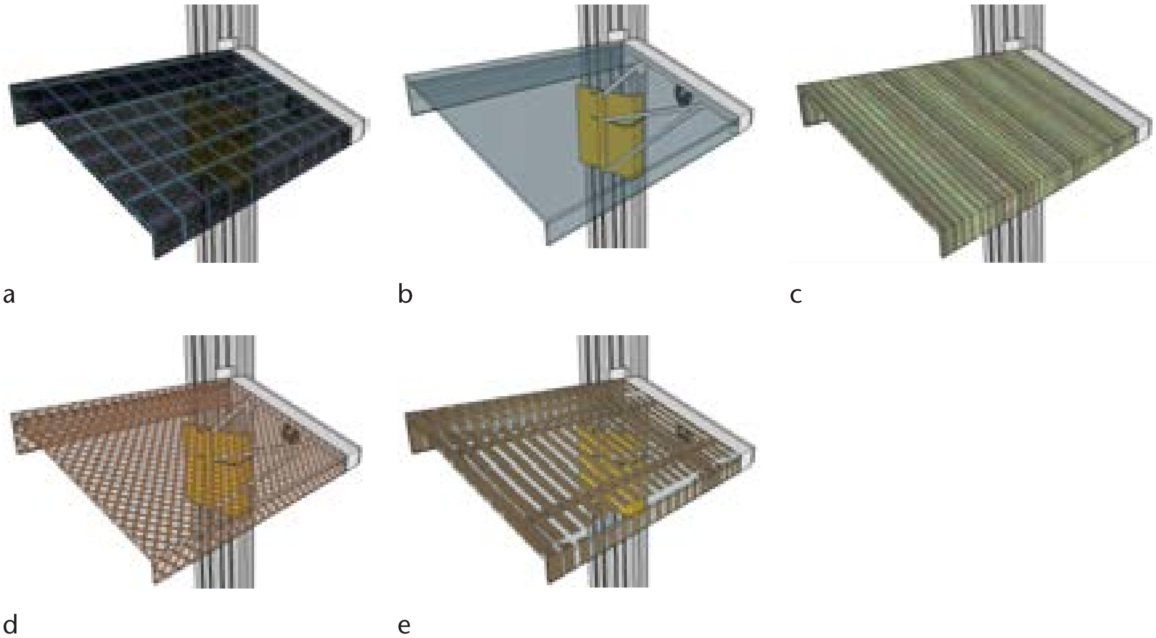
FIGURE 19. Material differences in panels: [a] photovoltaic, [b] Polly vinyl chloride, [c] straw, [d] mat, [e] wood.



(GFRP) and Photovoltaic cells that are embedded to these panels to collect solar energy and supply the energy required for the movement of the panels.

Finishing material of each movable panel could be different in order to meet various aspects of shading systems and aesthetic requirements. These material can be photovoltaic, Polly vinyl chloride, membrane, perforated metal, or natural elements, such as straw, mat and wood. Providing the system with photovoltaic panels can improve energy efficiency while use of Polly vinyl chloride, especially translucent ones, can improve the building's interior lighting even in freezing climates. Natural elements that are readily available can be more economical, eco-friendly and climatic. These materials can also decrease the weight of a dynamic system so that the size of the panels can be increased. [Fig. 18: [c]–Fig. 18]

CONCLUSION

The use of kinetic facades in buildings provides architecture with opportunities to improve a building's energy consumption, adaptability with environmental changes and users' requirements. The employment of smart skins in architecture have developed rapidly in recent years and is considered as a multi-disciplinary practice in architecture that is created by the integration of design, architecture, art, engineering and information technologies. This paper has applied the concept of changeable façade system to educational buildings. A changeable mechanical curtain wall was designed and developed to provide a comfortable educational environment. The main feature of the proposed system is its adaptability with environmental changes and various functions. It can not only open and close but it can also be transformed into various configurations by means of a simple kinetic operating system in order to respond to specific functional requirements, such as different educational programs that are that occur in a single space. In order to gain a high degree of flexibility, the curtain wall panels can be rotated 45 and 60 degrees in addition to their horizontal and vertical movement. The use of inclined tracks in the supporting structure make this free form movement possible. The connecting chains (central cable) of each panel placed at their end points are the key element in curtain wall movement. The whole kinetic system can be stacked and stored on the sides of the façade and create a fully transparent view to the outside.

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