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Article

A computational design strategy for integrated façades

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ABSTRACT

Over the last decades, computational methods have provided significant potential for integrated façade systems with energy efficiency, the generation of numerous alternatives, the optimisation of complex requirements, and the inspiration of creativity in architecture. In this sense, the study addresses two primary issues. First, conventional methods are inadequate in a holistic perspective of the multiple objectives of façade systems. Second, poorly designed or transformed media façades are a common problem in many developing countries. This study developed a design strategy for an Integrated Façade System (IFS) that consists of (i) simulation, (ii) analysis, and (iii) optimisation stages in a feedback loop. This design strategy was implemented to integrate the façade in terms of multiple data based on functions. The methodology is organised into two main sections based on the urban scale fieldwork and test of the suggested strategy through the case study. The fieldwork has been done to determine the case study building in Istanbul. Two additional façade functions, media display, and solar shading are chosen here to investigate the constraints, correlations, and consistency of multifunctional integration in a façade system. The finding showed that the developed IFS can contribute to the use of factual data as a design input. Another result showed that this IFS decreased solar radiation by 51% during the summer period. This algorithmic system has flexibility and affordance that refers to enhancing building performance within different contexts.

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INTRODUCTION

Computation has become a part of the design process with the ubiquitous use of digital tools and systems in architecture. With the inclusion of these tools and systems, design cognition has been important as the product. When the design process is well-defined, cause-effect relationships, criteria, objectives, and rules have more impact on the product. Although subjective design outcomes remain unpredictable, it ensures that precise results are achieved more than ever. The limitations are eliminated by using various types of data as input in the preliminary design phase and evaluating multiple factors together computationally. The data obtained from the simulation is the most accurate data, but it is less adopted in general practice due to its time-consuming (Roudsari & Pak, 2013). Because of the gap between the simulation results and the design process, the value of an integrated

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approach appears to remain incomplete. The visualisation of the simulation provides quantitative data as a design parameter at this point (Gadelhak, 2013).

There are many studies on computational approaches for daylight, energy and thermal performance of façades (Hudson, 2008; Brotas & Rusovan, 2013; Khorasani et al., 2014; Caetano & Leitão, 2016; Alagoz & Beyhan, 2020; Karakoc & Cagdas, 2021) due to the requirements for successful management of the impacts of environmental factors. Besides its performance requirements, the façades also provide communication with the environment as the shell of the building. In this context, there are many different objectives that need to be considered together, such as environmental factors, cost efficiency, sustainability, and interaction. Conventional design methods are inadequate in a holistic approach to these multiple and complex objectives. That is a common problem that affects the flexibility and resistance of the façade negatively.

This paper reconsiders the poorly designed façades from various aspects. It develops a design methodology with a holistic approach to integrated façade in terms of multiple data based on functions. In light of these explanations, the aim of the study is to investigate the integration of multiple parameters on the façades at the early design stage by enabling quickly generated alternatives. For a comprehensive evaluation, this study has implemented a new integrated facade design and investigated its effect on indoor solar irradiation. The study also contributes to the literature with a reasonable design strategy based on a computational approach by including simulation tools in the theoretical and practical framework.

THEORETICAL BACKGROUND

Envelopes, shells, layers, or skin—most notably façade—reflect a critical overlap between performance and aesthetics (Zemella & Faraguna, 2014). Façade, as an interface or mediator, fulfils a multitude of additional functions concerning the environmental performance of the building and the user requirements (Boeke et al., 2019). Since it has a significant role in building performance and interaction, the façade is a critical element in the design process. Several studies have documented many developments in the complexity of façade design over the last few decades (Ochoa & Capeluto, 2009). The current literature contains numerous modern systems, methods, and cases for design, restoration, transformation, and reconstruction.

Glass curtain walls are one of the modern, ubiquitous façade systems that have been mostly seen in metropolitan cities. Despite providing shade control through new technologies such as electro-chromic glass, most glass curtain walls need additional control (Jamrozik et al., 2019). Sunlight and solar radiation can be useful in providing natural light and heat for buildings, reducing the need for artificial lighting or heating. This can reduce energy use and emissions. However, excessive solar radiation can result in overheating, which may need to be countered with energy-intensive cooling, or can cause glare, a form of visual discomfort experienced when lighting is excessively bright. Correspondingly, shading devices are one of the main elements of glass façades (Tovarović et al., 2017) to provide optimal use of daylight and solar radiation by controlling solar gains and reducing the negative effects of sunlight through façades (Kuhn et al., 2001). Solar shading strategies differ in geometry and pattern (Brotas & Rusovan, 2013), movement with dynamic parameters (Grobman et al., 2017; Hosseini et al., 2019), and material (Pelaz et al., 2017; Gunawardena & Steemers, 2019). By networking solar performance, interaction, and industrial production within an integrated system, the affordance of the façade has increased in accordance with the new principles and computational design methods.

The integration of the additional functions mostly refers to the "Double Skin Façade" (DSF) as an overall system. Within the scope of the different façade functions and characteristics, DSF systems are examined for two main reasons: environmental and aesthetic (Ahmar & Fioravanti, 2017). The distinction between these two reasons is related to the environmental performance of the building façade and interaction on an urban scale. For each function, the technology and computational design tools have been intertwined.

The first part of this study refers to enhancing building performance based on the defined dynamic parameters in environmental conditions (Gerber et al., 2017). In the second part of this study, media displays offer great potential for interaction as a new form of communication in the digital age (Globa et al., 2019; Halskov & Ebsen, 2013). Digital out-of-home (OOH) advertising, including media displays, has the fastest-growing impact on marketing. According to research by Foursquare, total OOH spending will reach $7.74 billion (growing by 15%) in 2021 due to the impact of the COVID-19 pandemic (Johri, 2020). Therefore, the global importance of media façades is growing over time. The interactive possibility of the media façade is composed of different elements: such as digital display skins with light-emitting diodes (LED) and kinetic solid panels. As in the research case, many developing countries, and their metropolitan city centres have common problems with poorly designed or transformed media façades. It is possible to characterise the media facades on an international scale in terms of their functions (commercial, economic, political) and technical descriptions (physical-digital, temporary-permanent, partial-entire façade, etc.). For example, it is seen that media facade examples are mostly used for construction sites to make restoration and rehabilitation works invisible (Figure 1). However, many examples, especially economy-driven,

Figure 1. Exemplification of temporary/permanent media façades in Madrid City centre.

are not temporary. There is a lack of sustainable solutions by ignoring thermal comfort and visual interaction (Cikic-Tovarovic et al., 2011).

The development of new technologies, materials, and fabrication methods has led to new integrated systems in architecture. Integrated Façade Systems (IFS) as a component of shading devices (Ibraheem et al., 2017) are facades that incorporated different technological solutions lower environmental impacts and improve façade performance (Ibraheem et al., 2020). IFSs offer heat gain control which leads to administer air-conditioning loads, and glare control while the use of natural light is maximised (Ibraheem et al., 2017).

The main concern of this study is to develop a holistic view of IFS by concerning the potential of the computational design approach by discussing two functions together. This holistic view includes visibility distance and resolution for media function and shading function to control solar radiation. Consequently, the hypotheses are as follows:

Hypothesis 1. A computational design approach formulated by analysis, synthesis, and evaluation steps with a holistic approach has the potential to be a tool for the early design phase of integrated façade systems.

Hypothesis 2. Perforated panels such as IFS can serve as both media display and solar shading devices.

Hypothesis 3. Solar radiation simulations and analysis for designed IFS for media display function enable improvement of solar control performance of existing façade.

RESEARCH METHODOLOGY

The methodology of this study consists of two main sections based on the literature review and the case study. In the first section, the design framework is of IFS for the integrated media façade to examine the H1 and H3. As shown in Figure 2, the framework provides context, data analysis methods, and simulation tools. Fieldwork and the significance of media façade topics are examined in the second section. Façade functions, attributes, and project information are identified regarding the integrated media façade.

This study was carried out using some results of the computational design workshop five different student groups (consisting of three or four students who have doctoral degrees) participated. The workshop was organised in cooperation with the university and industry in 2019–2020. It was aimed that the participants proposing the facade design by thinking over and discussing problem definition, ideas, and production processes. The current production potentials (such as robotic and CNC) and requirements of the industrial environment were shared with the workshop participants during the preliminary information process. Robotic fabrication and material resources (panelization) have an impact on the process regarding the production and testing of the prototypes (H2). The project proposals from the groups were a PV-supported dynamic shading system, an interactive campus shell, and wave-based shading arches on the deck. Besides these, the researchers' project for this study was the environmental media façade system. Façade/shell/skin design proposals are created as IFS with the function of mobility, interactivity, and energy efficiency.

This study suggests interdependent façade functions and dialectic for IFS with the shading function and media display working together to enhance the functionality of the façade. The suggested integrated façade system in the parametric design framework consists of (i) data inputs, (ii) simulation & analysis, and (iii) panelization steps (Figure 2) for the early design phase. As sub-attributes, shading function and media display are identified to improve façade affordances and visual interaction. By networking these attributes, the framework has the capability to generate numerous possibilities for the design solution. This algorithmic process is reparametrized according to the percentage of display and resolution type (low-high). The visual custom scripts were developed based on parameters

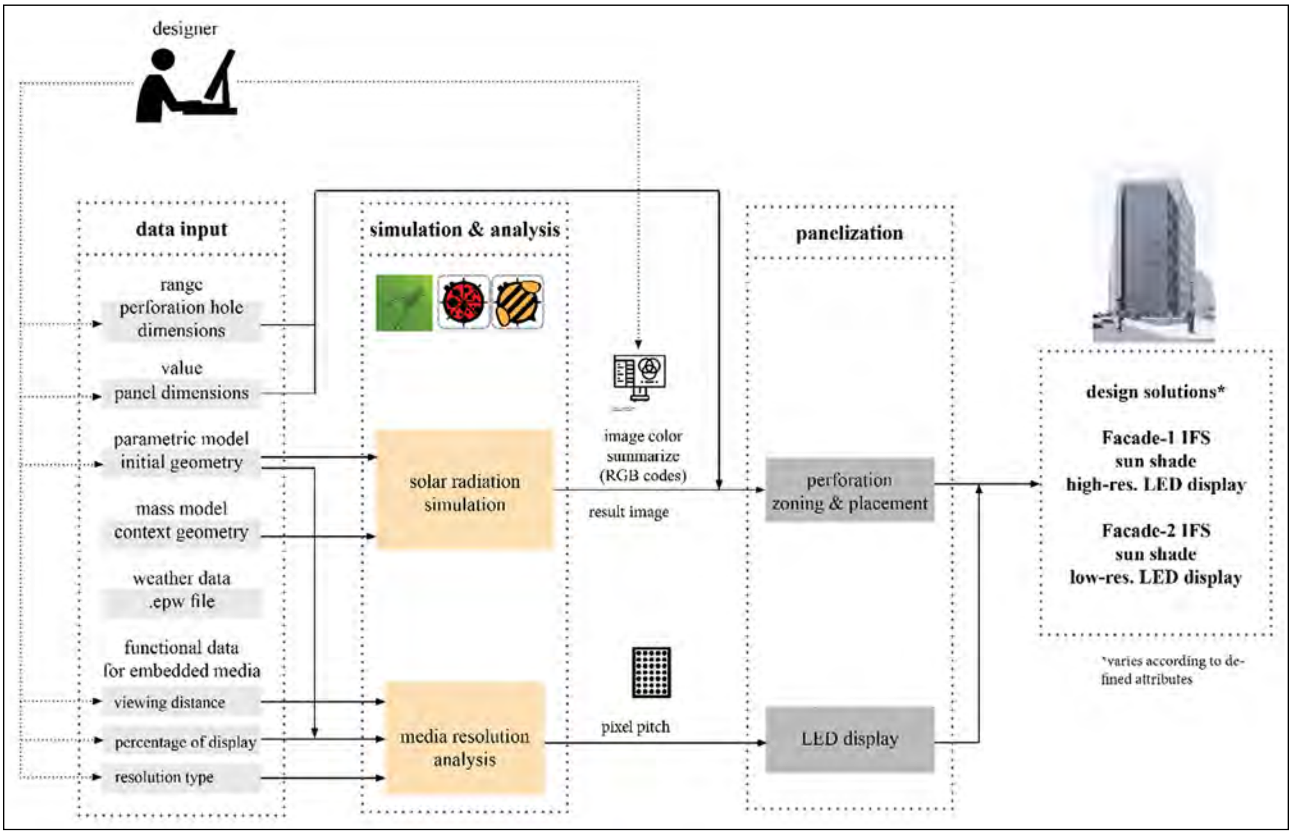


Figure 2. Design framework.

and attributes, sub-attributes, simulation, and analysis to allow for an automated generation of façade panels.

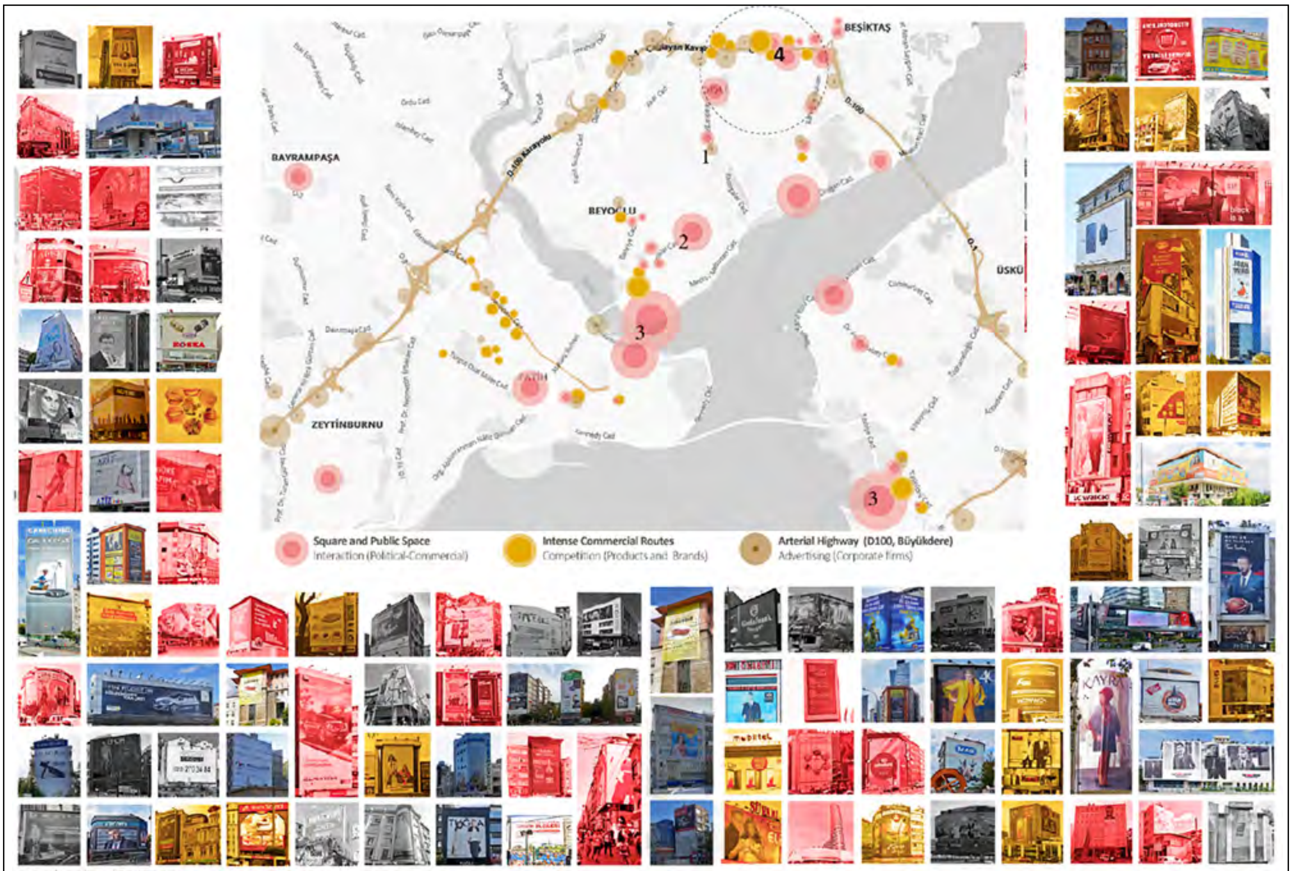
FIELDWORK

The terms metropolis and historical topography refer to the international economy, crowded population, urbanisation, and different conflicts within the topography. In particular, media façades and urban commercial economies are in a mutual relationship with each other regardless of public/private user requirements. There are different approaches to this common urban problem that refers to urban identity, screens in capitalism, etc. (Derviş et al., n.d.). However, the issue of meeting the commercial requirements, which leads to conflict with the performative functions of the façade, is one of the most significant architectural problems of media façades. The design approach has to reduce the negative effects of the media interaction on the primary functions of the façade and the sustainability of the building and provide flexible systems that add value to the building.

The research site is Istanbul which is among the world's metropolises with its cosmopolitan, diversified, and historical topography. Fieldwork clarified the significance of media façades on a metropolitan scale. Here, media examples with high levels of interaction applied directly to the surface, such as murals and graffiti, are excluded from the scope of the study because of the blind façades. In addition, the media façade layers of the first floor show a general situation in the trade zones. This situation is questioned in the existing literature through the perception of the cities and streets at eye level.

The fieldwork to determine sample buildings has examined media façades on medium and high-rise buildings in metropolitan areas of Istanbul. Although these applications are generally seen on one façade, examples with two and three façades are also included here. In this direction, general determinations of the situation were conducted for the public spaces. The mapping of the urban modern and historical parts of the city provided us with intensified points. As shown in Figure 3, the media façades of the buildings are classified into three types: square and public space (Type 1), intense commercial routes (Type 2), and arterial highways such as D100 (Type 3). This mapping was created to highlight the commercial concerns with public interaction in the media façade layer of the city. Therefore, the close environmental openness and orientation values of the media façade, which will provide public interaction, relate to the sunbathing values. Particular examples in the double-direction traffic flow (Figure 3, Types 2 and 3), corner parcels (Figure 3, Type 1), and intense public spaces (Figure 3, Type 1) are at a critical point with media façade potential.

All constellations have in common that they aim primarily



Map baseline: IBB GIS System
Pictures: Google and Yandex street views (2011-2014-2020) supported with field experiences.

Figure 3. Fieldwork and mapping.

to interact with the objections of commercial, political, creative, social responsibility, informing, aesthetics, etc. Nişantaşı Shopping centres' media façade (1) commercial, Marmara Hotels' roof media box (2) mark, Karaköy, Eminönü and Kadıköy squares (3) political and commercial, Mecidiyeköy-Levent high-rise office buildings and shopping centres' media façades (4) political, commercial, creative, and aesthetics are just some of them.

The results of the analysis according to the three categories showed that intersection points between the Mecidiyeköy high-rise commercial zone and the D100 arterial highway have all three evaluation categories and they condense at these intersection points. The building located in the intersection of busy streets was determined for the case study to investigate the media and shading functions of the façade. This building is a corner building and has three facades facing the streets. The corner structure positioned towards the south is analysed in detail for this case study.

CASE STUDY

The case study involves a computational model that is linked to the parameters and simulation tools in Rhinoceros™ and Grasshopper (as fundamental computational design tools). The design flowchart details the parametric model and IFS components by including data input and design parameters.

A case building is a seven-story building and located in the central city square near the D100 viaduct. This building has a high window wall ratio on its east, north and south facade but has no window west facade. The solar radiation on the working plane changes according to the direction of the facade, window wall ratio and external shadings. The south facade is the most effective facades for solar radiation control. In the scope of this study, the IFS, PVC perforated film banners, covered the external surface of the eastern façade (Façade 1 (F1)) and the southern façade (Façade 2 (F2)) excluding the entrance face of the first floor. The dimensions of the eastern façade (Façade 1) are 9 m wide by 28 m high, and southern façade (Façade 2) is 18 m wide by 28 m high. The building's gross floor area is 1400 m2. The ground and first floor are occupied by a patisserie, while the second through seventh floors are occupied by an English course.

Data Input

Research has multimodal data related to shading and media interaction. Most of the data is directly from the current condition, but there is manipulative flexibility for the designer. Therefore, panel surfaces are determined according to the simulation results. These simulations are composed of two parts one of them is the optimisation and the second is an analysis of the effect of the developed IFSs. For optimisations, one of the joint parameters is embedded media data, which refers to pitch value according to media resolution and human-façade distance. Another joint parameter is solar radiation. These two parameters, along with another interdependent input -façade size- provide high or low resolutions by pixel pitch value (Svilainis, 2018). IFS data inputs are linked with shading and embedded media sub-attributes.

Regional climate data as a weather parameter is used for the determination of the hole size of IFS. The file with the "epw" extension is obtained for Istanbul located in Region 6, from the webpage of WMO (World Meteorological Organization) (Climate.OneBuilding, 2019).

The solar radiation has been calculated for all years to determine the shading effects of IFS in both the summer and winter periods. The calculation period was settled from 8:00 to 17:00, depending on working hours in order to provide proper shading by considering user requirements, since the case is an office building.

The reflection coefficient of building surfaces is determined according to standard EN 17037 (Organization, 2018). The reflection coefficient of ceilings is p=0.9, walls are p=0.7, floors are p=0.2 and shading panels is p=0.5. The visual light transmission of window glass is 0.75, thermal transmittance (U value) is 1.8 and solar heat gain coefficient is 0.63 according to TS 825. A detailed explanation of the properties of shading panels is given in "Panelization" section. For simulations, the properties of the building and panels were input on the 3D model. The panels were located 0.55 m away from façade for calculations.

Design Parameters

The use of two façades in different directions with different attribute values reveals the applicability diversity of this method. The main differences between the façades are the resolution of the media display and the percentage of the display surface. F1 is perceived from the human point of view. Regarding media display on this façade, high-resolution is required to allow readability. However, F2 is perceived during the rapid movement of vehicles due to the viaduct in front of the building. Therefore, a low-resolution display is sufficient to make it possible to get more sunlight. The shading function and embedded media sub-attributes are defined for the design workflow through (1) solar radiation simulation, (2) media resolution analyses, and (3) panelization steps (Figure 4). Each step is linked algorithmically to the next step as a visual script on the computer with an Intel i7 processor, 32 GB RAM,

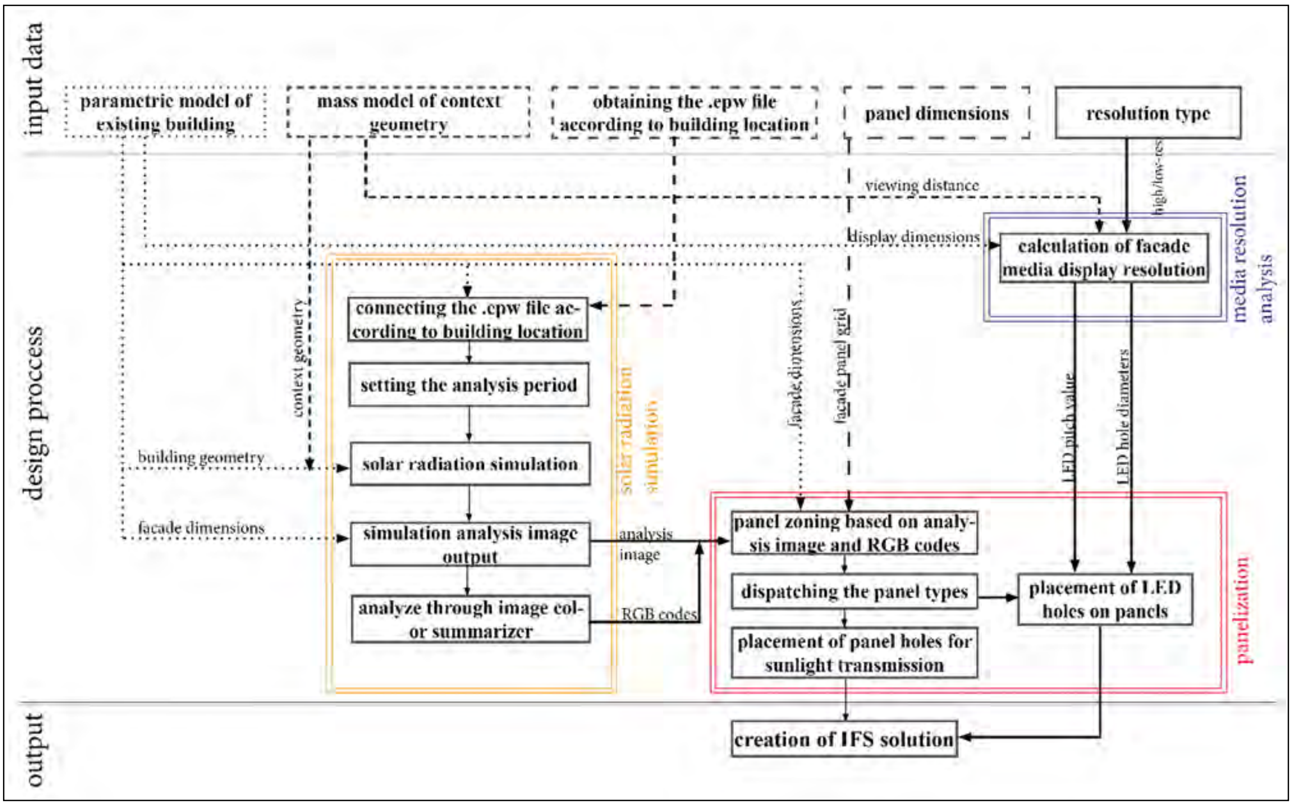


Figure 4. Design flowchart.

and NVIDIA GeForce RTX 2060 graphics card technical specifications.

Simulation

The first part of the simulations aims to determine the holes of IFS according to optimisation results. The optimisations have been done by calculating media performance and solar radiation performance (detailed information is given in Panelization). The solar radiation is reflected, absorbed, and transmitted after comes to the façade. A big part of it is reflected or transmitted depending on the features of the facade (window wall ratio, properties of shading devices). The transmitted and reflected solar radiation are related to each other. Therefore, in the first part, the calculations have been done to determine the incident solar radiation on the façade. The second part aims to compare the effect of developed IFSs after optimisations on the working plane. The second part focused on the analysis of transmitted parts of solar radiation by calculating the solar radiation on the working plane. The input data and settings for the simulations such as weather data, calculation period, building properties and IFSs properties are given in data input and panelization.

Firstly, for optimisations, the simulation tools were utilised to analyse the amount of solar radiation received by a façade surface through parametric strategies. The building was modelled by using Rhinoceros 3D with Grasshopper. Solar radiation was calculated with the Grasshopper3D (Rutten & McNeel, Rutten, 2007) add-on Ladybug (Roudsari & Pak, 2013)that uses GenCumulativeSky (Robinson & Stone, 2004) for the calculation of radiation amount. Building and site 3D massing models were connected to the LadyBug Radiation Analysis component. This add-on was used in many scientific studies (Anton & Tanase, 2016; Perini et al., 2017; Vartholomaios, 2017; Panya et al., 2020) and its reliability has thus been demonstrated.

Because of the extensive calculations, the consequences of physical conditions are frequently deferred until the next phases of architectural design. These add-ons allow for physical conditions to be effectively incorporated into the early design phase as well. This tool was used to simulate solar radiation for each geometrical input. The ray-tracing capabilities of Radiance (Reinhart & Walkenhorst, 2001) were used for simulation with the setting of a 2 m × 2m grid value in order to take advantage of the correlation between output and façade panels. The image output of results is interrelated with the façade width and height dimensions provided by the simulation. The colours of the image output were evaluated with their numerical equivalents on the legend (Figure 5) which gave us the opportunity to associate them with the panel holes.

In the second part of simulations the solar radiation was calculated by using Ladybug Radiation Analysis component to evaluate the effects of developed IFS. The calculation surfaces (working plane) were determined 0.85 m away from floors by reference working plane as given in standard EN 17037. The grid size of the calculation surface was 0.5 m × 0.5 m. As a result of the grid sizing, there are arisen 1085 test points on the working plane for each floor. The solar radiation results of the working plane have been visualised in terms of results with and without IFSs. The results were also graphed according to floors and total building. The results have also shown in a graph for floors and the total building.

Media Resolution Analysis

Optimum visibility and resolution on media façades become important factors as they affect the visibility of the medium (Lee & Sul, 2017). The resolution value depends on the centre-to-centre distance between two pixels, i.e., the pixel pitch value. The distance from the viewpoint to the screen creates closer pixel gaps. There are several assumptions to calculate the optimum range of pixels according to the distance (every 1m away from the screen the pixel pitch should increase by 1 mm). The optimum viewing distance is determined according to screen dimensions, and the pixel pitch value. In this direction, an algorithm is generated that provides an 80 mm pixel spacing value for the high-resolution display of F1.

Low resolution is tested to allow readable images, videos, and text to be displayed. For F2, a 250 mm pitch value is defined according to the two-story height along the façade. Each hole radius is 50 mm for LED pixels. The black and white image with text is placed on the façade surface via the image sampler component. It is suggested that the following properties can be applied in the production of the designed panels. They can be produced as separated panels are dimensions 0.8 m × 3 m, but panel size can also be customised. According to 8000 mm × 3000 mm dimensions and a pixel pitch of 250 mm, the actual pixels are 32 pixels × 12 pixels for each panel. The weight of the mesh screen will be between 2 and 5 kg/sq. m. The colour processing can be between 12 and 16 bits. IP rating should be IP 65. Their scan mode is static, and their estimated consumption is between 200 and 600 W/sq. m. supply from AC 100–240 V; 50/60 Hz with 7.5 V DC (*HM Series – LED Pixel Display Screen, n.d.; M6 – LED Mesh Screen, Soft LED Display, Transparent LED Mesh*, n.d.).

Panelization

Simulation outputs and pixel values are used for panelization parameters. Image output is analysed and evaluated via the “image colour summariser” and “image sampler”. The colour summariser is a method that reports a summary of colours in an image using clustering, to group similar colours together and derives a set of colours that are representative of the image, histograms of colour

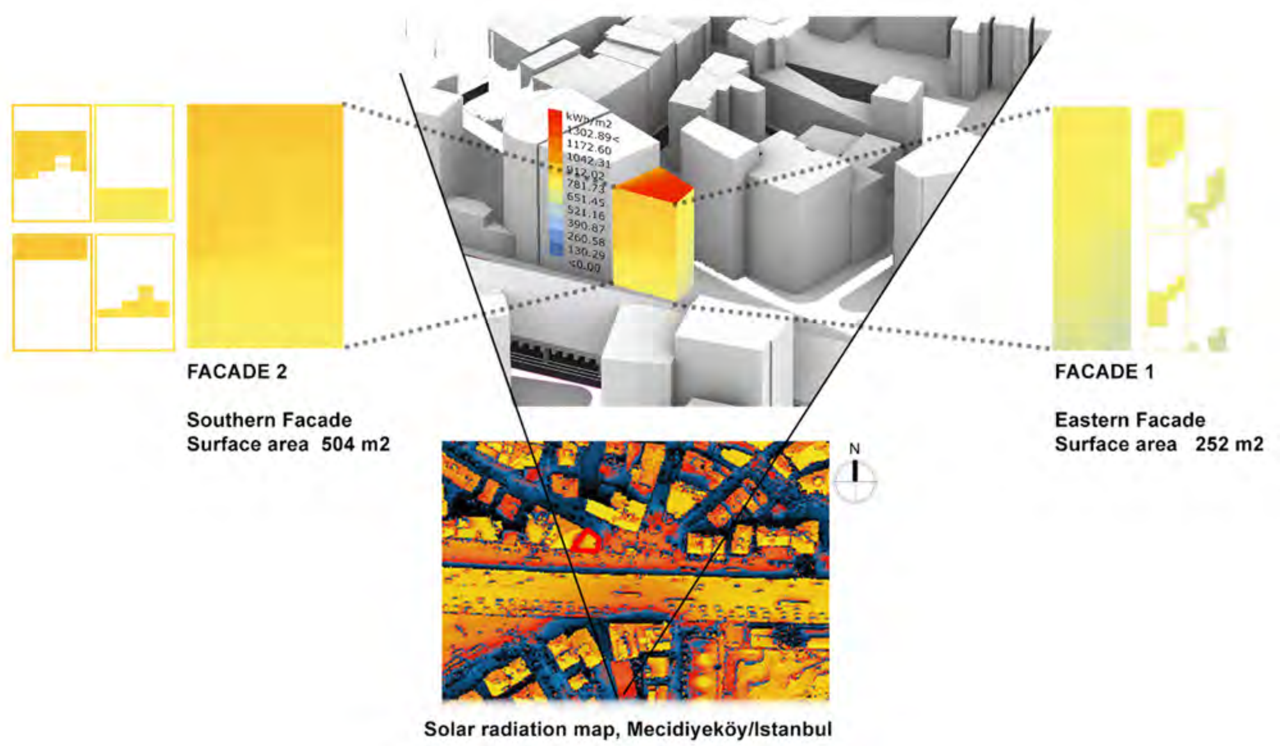


Figure 5. Simulation of solar radiation and colour clusters.

components (Krzywinski, 2018). Four colour clusters were determined as shown in Figure 5. There are two correlations: the panel gaps with colours in the algorithm, and the number of panel types with standardisation.

Simulation outputs (transformed RGB—red, green, blue—codes in coordinates) and measurements were used to calculate the solar transmissions on the panel. The coefficient value (0.2) corresponds to the colour with the highest solar irradiation value and indicates the minimum solar transmission. In this way, the rate of sunlight transmissions provided data to the algorithm. Each panel type was primarily divided into four zones that were adequate for the computer capabilities used in this research. Panel grids related to the colour clusters, measure 200 cm × 150 cm for both façades. In the final stage, 84 panels were formed with 8-panel types in F1 (Figure 6). On the other façade (F2), 144 panels were formed with five-panel types. While the whole data set was inputted to the parametric system, IFS panels were created by the rule of smaller maximum sunlight transmission hole diameter than the pitch value set by the algorithm. The LED placement was defined by pixel value as an input at this stage. After subtraction of the LED holes from the panel surfaces, the rest was perforated for light transmission.

Details of the system (cable connections, application, maintenance, and automation) are designed based on the material of the panels. Perforated metal is to provide ease of production (Figure 7). Perforated metal material was used for shading panels to provide not only the enhancement of performance as a reduction of solar radiation (Mironovs et al., 2017) and noise (Sakagami et al., 2010) but also the additional function of communication through images (Kim et al., 2017). In this direction, panel types were created and tested with the help of the CNC machine system. With this test, the producibility of the metal panels within the CNC machine system was checked for rapid prototyping. The glossy material of shading panels has 50% reflectance (p=0.5) (3% in specular and 47% in diffuse). The RGB (Red Green Blue) values are 0.47, 0.48 and 0.48, respectively. The perforated media façades were simulated with the 3D building model. Then, the compatibility of the moving image with the number of pixels on the media façade was simulated on the Grasshopper-image sampler component. With this simulation, the relationship between any moving image that will be displayed on the façade and the number of pixels was tested.

RESULTS AND DISCUSSION

Over the last decades, a wide range of studies and applications on the façade has contributed to a new knowledge of categories with new notions and attributes. Computational design approaches that provide potential for simulation tools and systems have to broaden the research area with these new opportunities. However, there is a disconnection between the simulation results and the design process with

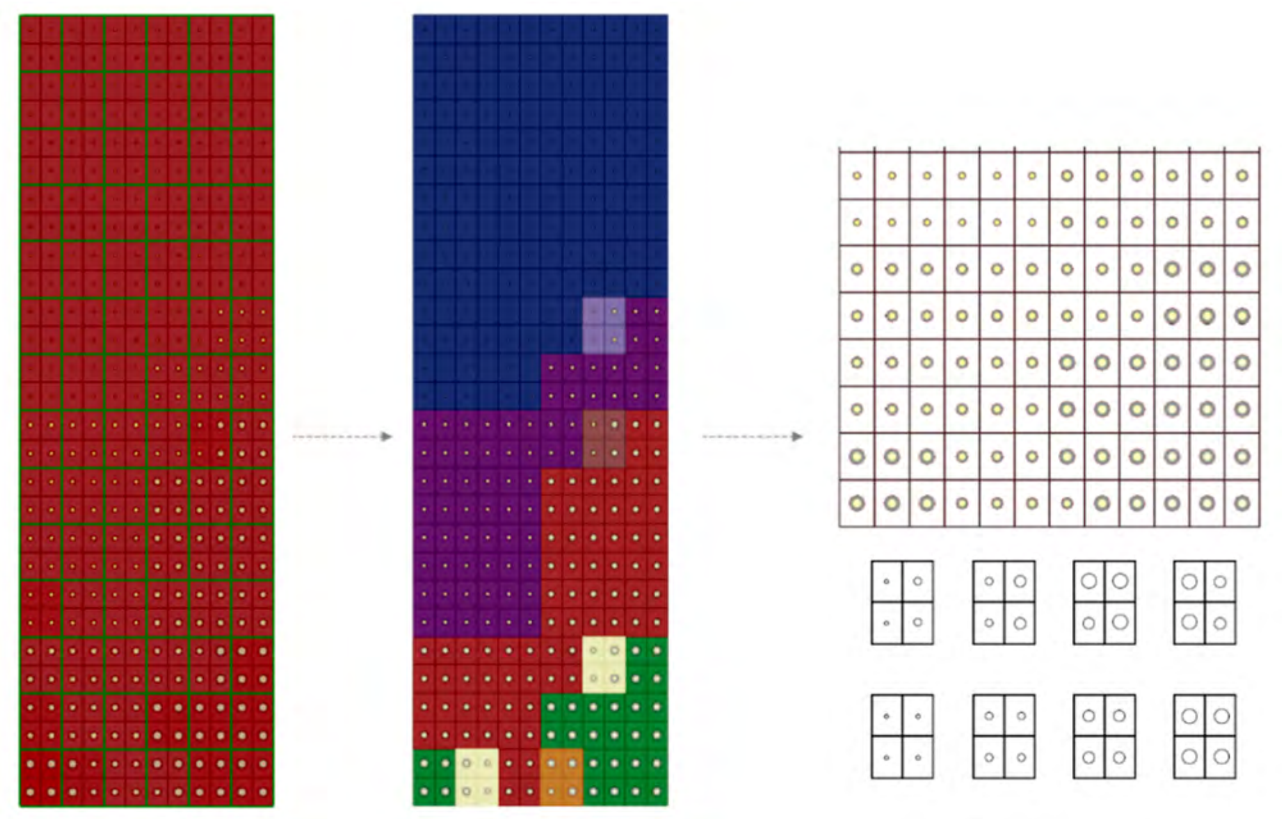


Figure 6. Façade 1 panelization based on simulation outputs and determining panel types.

the lack of a holistic approach (Roudsari & Pak, 2013) To achieve this holistic approach, this study developed an attribute-based IFS with the concern of shading and media functions. These attributes are represented as RGB codes and resolution values, which are fundamental design parameters and are integrated into the design process. Data conversion from RGB codes to the panel holes proves that the environmental conditions can be parametrically linked to the design framework (H1). H1 contributes to H3 by integrating the solar radiation simulation with display resolution analysis, which provides enhancement of current façade shading and media functions according to parameters (H3). The visualisation of the simulation on the model allows the use of it as a design parameter in the framework (Mallasi, 2019).

Although the fabrication stage of this study has not been completed, the affordance of metal panels is researched by observation of the production process of perforated metal panels (Figure 8) by partial mock-up attempts. The observed production process and other studies (Caneparo, 2014; Kalo & Newsum, 2014) have shown the ease of precise perforation on the panel. Besides the ease of production, moderating the solar gain (Blanco et al., 2019) also provides a potential for using the perforated metal panels on the façade (H2). Metal panel supports H1 with a wide range of sizes, both in length and width. It also provides flexibility to the design framework by allowing holes of different sizes on the panel for both sunlight and LEDs.

The existing façades of the case building are covered by PVC, which allows only one-way vision through the perforated banner. The design framework of IFS allows users to manipulate diameters and to see the user perception from the inside (Figure 9) and outside of the building. It also provides more daylight transmission than the existing façade through patterns with bigger holes compared to the existing PVC media system. This IFS model allows decorative perforation with a larger diameter with a lower resolution. This ornamental decision depends on the designer and users in the renewal process. F1 and F2 are compared according to their shading function performance by calculating the solar radiant exposure of each floor. With the IFS, the current disposable and poorly designed façade is replaced with a context-driven and sustainable solution.

Different applications based on the literature are analysed to clarify IFS impacts on the façade (H3). Essential parameters of IFS 1-2-3-4-5 (Tscherteu, 2008; Boeke et al., 2019; Bomfim & Tavares, 2019; Erkol & Sayın, 2021) investigated with the analysis matrix. Conceptual details of Environmental Media, PV Integrated, Green, Dynamic Shading, and Smart System Façades were associated with the façade functions (FF) to enhance their performance (Figure 10). The scope of this study was limited by the

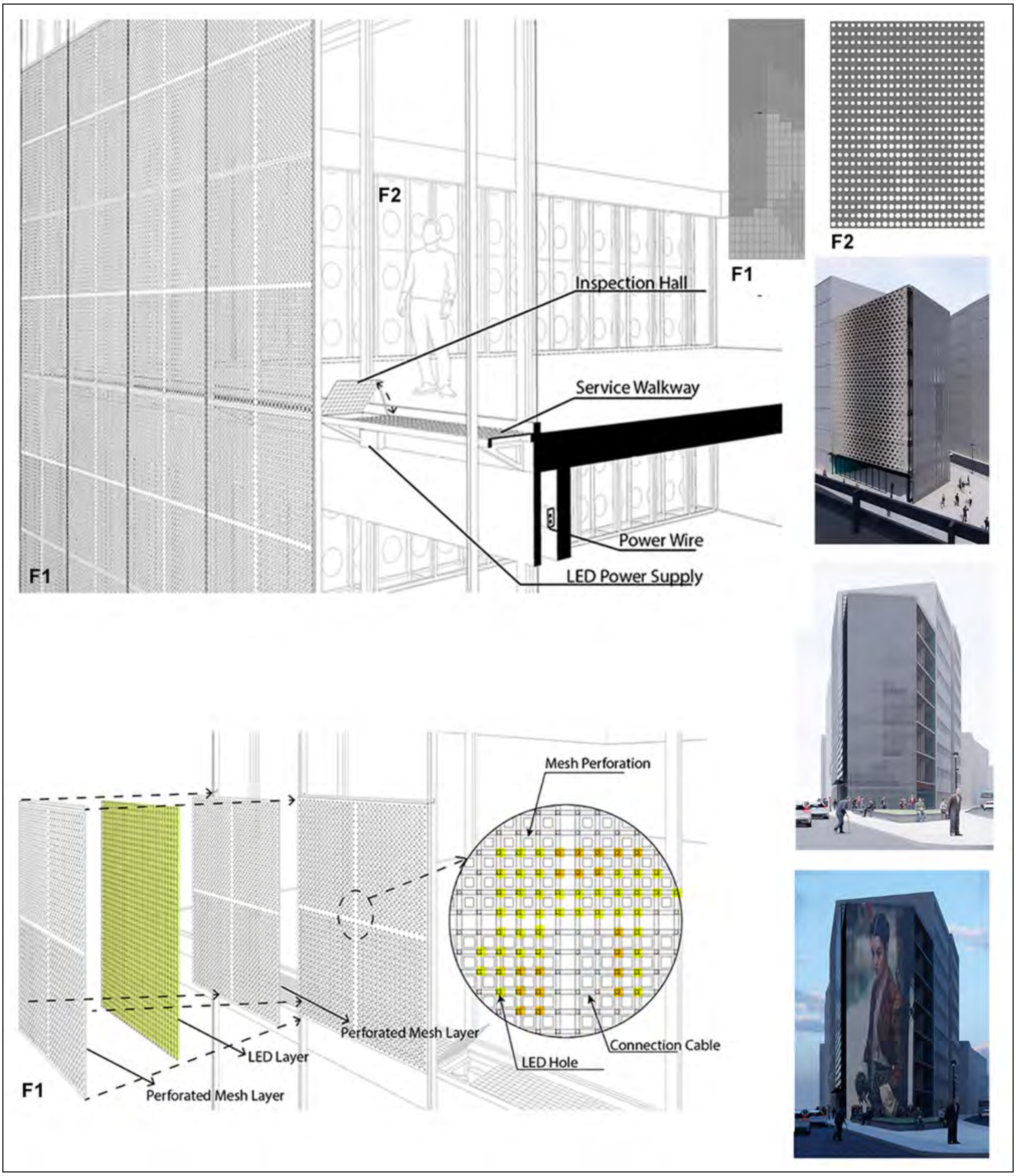


Figure 7. Perforated metal panel detail.

effect of IFSs on solar radiation. However, it should be remembered, solar radiation is, directly and indirectly, related to glare, air temperature, visual contact, energy consumption, and interaction. As shown in Figure 10, other studies in the literature have contributed to the IFS production model with different materials and methods, including various attributes. This conceptual table and other applications showed that media façades could be associated with IFS in an aesthetic, flexible, and sustainable way by using perforated metal panels.

One of the indirect findings of the research can also be discussed in relation to the identity of the city and the built

Figure 8. Perforated metal panels (Authors' archive).

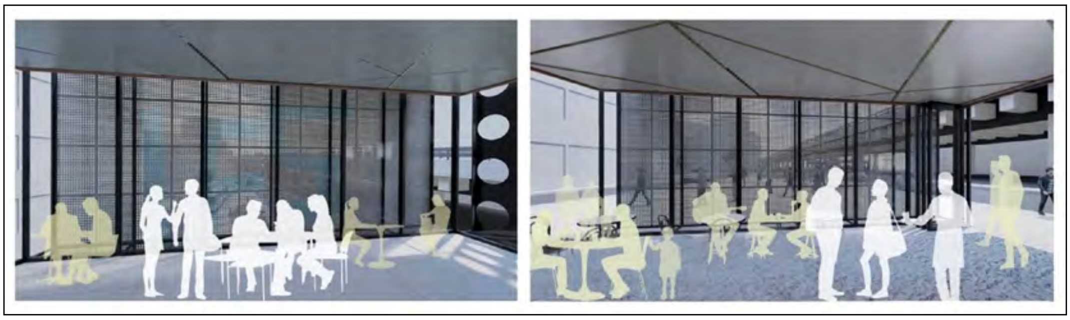


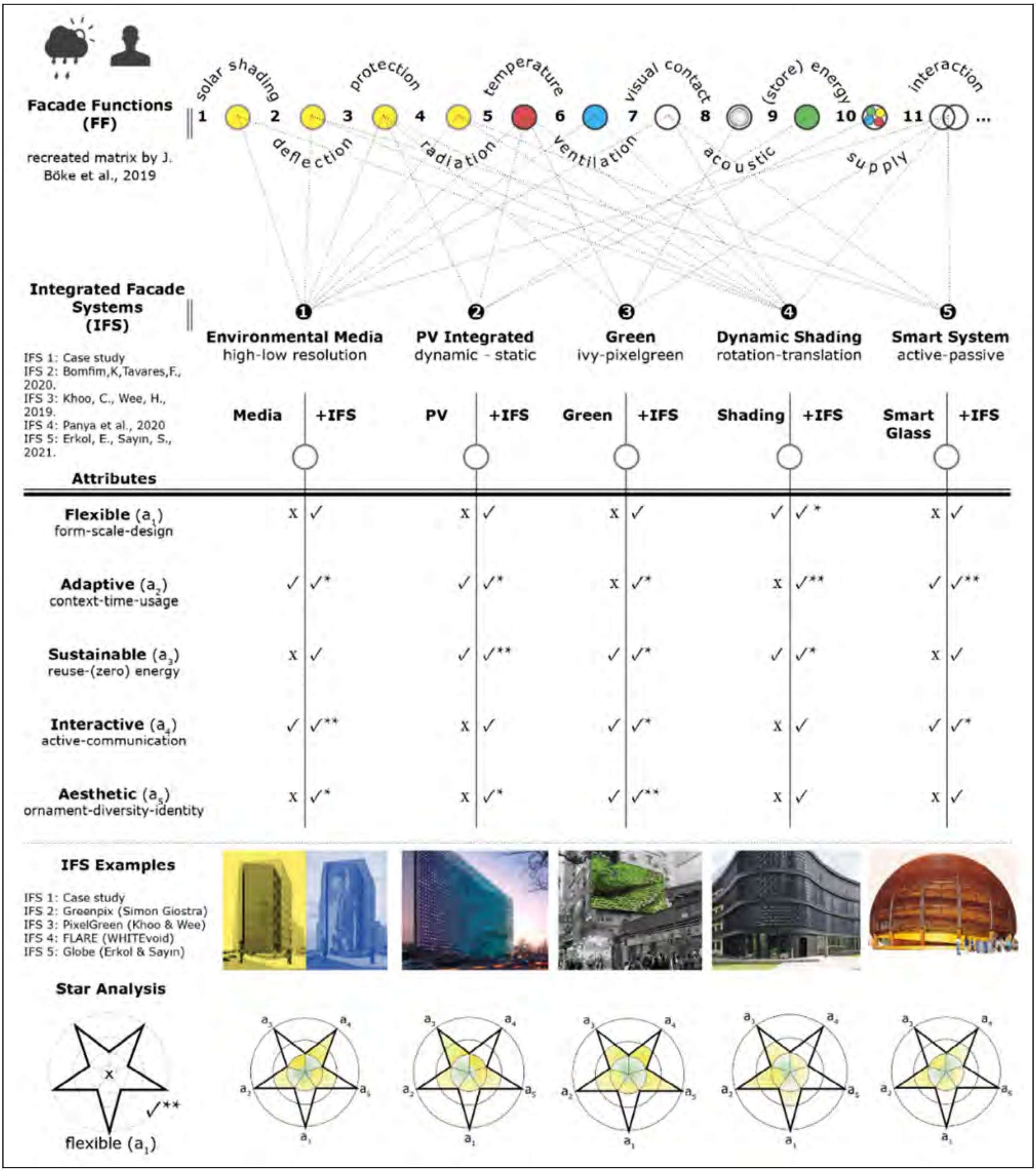
Figure 9. F1 and F2 interior demonstrations.

environment. In particular, fieldwork showed the importance of this subject in the scope of Istanbul. Besides, there are numerous and continuous discussions based on literature, urban transformation, gentrification, interventions on historical topography, academic perspectives, associations, and daily life. As a current situation, the green wall applications along the Istanbul highways have been removed by the municipal decision in 2020. Different criticisms were brought as justification, such as the financial and maintenance burden compared to its ecological benefit and its pure visual function. Even such non-building—public—façade applications, with significant annual expenses, can be associated with the research approach and findings. The need for individual advertising billboards and green walls along the highway should be addressed in a sustainable approach within IFS. The "Konuşan Duvarlar" project (IBB, 2020) instead of the high-cost green walls is also a matter of debate from a different perspective. This current debate shows that research findings mainly discussing interaction and shading have great potential for interrelated subjects like spatial identity and environmental psychology in the built environment.

Another research discussion mainly focused on the tests for the media interaction and the solar shading function of IFS compared to existing façades (H3). The facades should be designed to control solar radiation to provide thermal and visual comfort and so decrease energy consumption. Solar radiant exposure was evaluated in terms of the effect of the perforated metal media façades in terms of the shading function. Using the Ladybug plug-in in Grasshopper software, the effect of solar radiation is compared to the case with and without IFS (Figures 11 and 12). The baseline façade is referred to as the glass curtain wall, current PVC coating is not included for the baseline façade.

The solar radiation was calculated for all year, summer, and winter periods. So, the results can be compared according to the effect on two periods. The summer period was determined as June, July, August, and September which have mean air temperatures >25 C°. The winter period was determined in November, December, January, February, March, and April which have mean air temperatures <15 C°. Since the months are determined according to mean air temperature May and October are included in these two periods. In the other words, the summer period is from May 15th to October 15th and the winter period is from October 15th to May 15th.

The results showed that solar radiation value decreased from 272/ sq. m. to 116/ sq. m. When panels are used total solar radiation (total of all floors) has decreased by 57% for both all year and summer periods. The difference in solar



Attributes	Media	+IFS	PV	+IFS	Green	+IFS	Shading	+IFS	Smart Glass	+IFS
Flexible (a_1) form-scale-design	x	✓	x	✓	x	✓	✓	✓*	x	✓
Adaptive (a_2) context-time-usage	✓	✓*	✓	✓*	x	✓*	x	✓**	✓	✓**
Sustainable (a_3) reuse-(zero) energy	x	✓	✓	✓**	✓	✓*	✓	✓*	x	✓
Interactive (a_4) active-communication	✓	✓**	x	✓	✓	✓*	x	✓	✓	✓*
Aesthetic (a_5) ornament-diversity-identity	x	✓*	x	✓*	✓	✓**	x	✓	x	✓

Figure 10. Schematic representation of the IFS attributes and correlations.

radiation between the summer and winter periods is 7% without panels and 6% with panels. As expected, the panels decreased the solar radiation for all year, even in winter period.

The results showed that the first floor has higher solar radiation than others under conditions "with IFS panels". The reason for that is the calculations have been done considering that the first floor hasn't panels on its south facade as different from other floors. With the using IFS panels, the solar radiation has shown a decrease towards the upper floor except on the last floor (seventh). The panels have smaller holes towards the last floor and this explains the decrease in solar radiation. The panels are away from the facade 0.55 m, and this leads to solar radiation getting

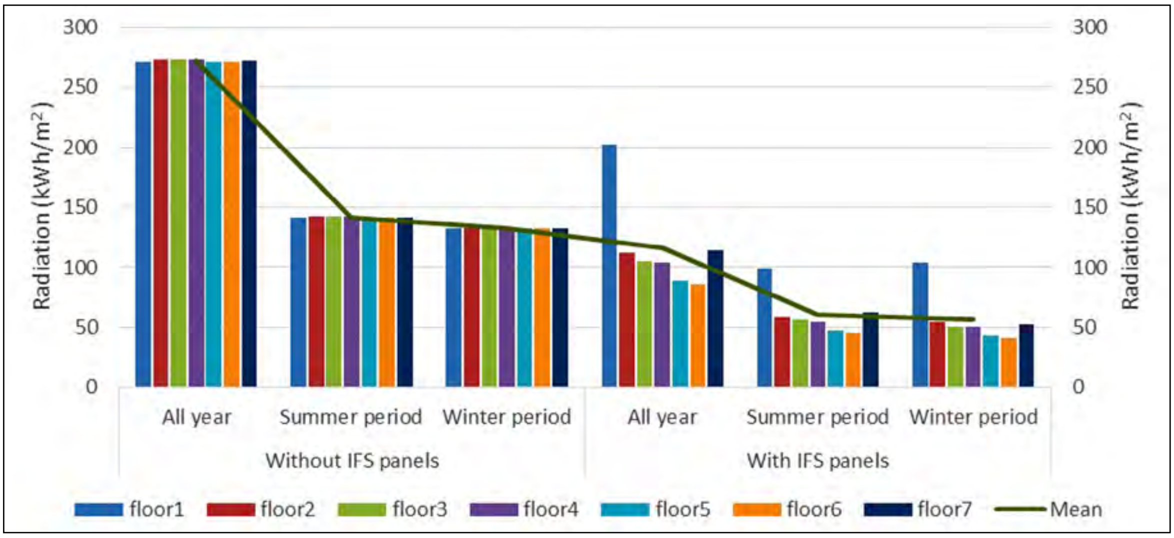


Figure 11. Solar radiation of floors without and with IFS panels for all year, summer period and winter period.

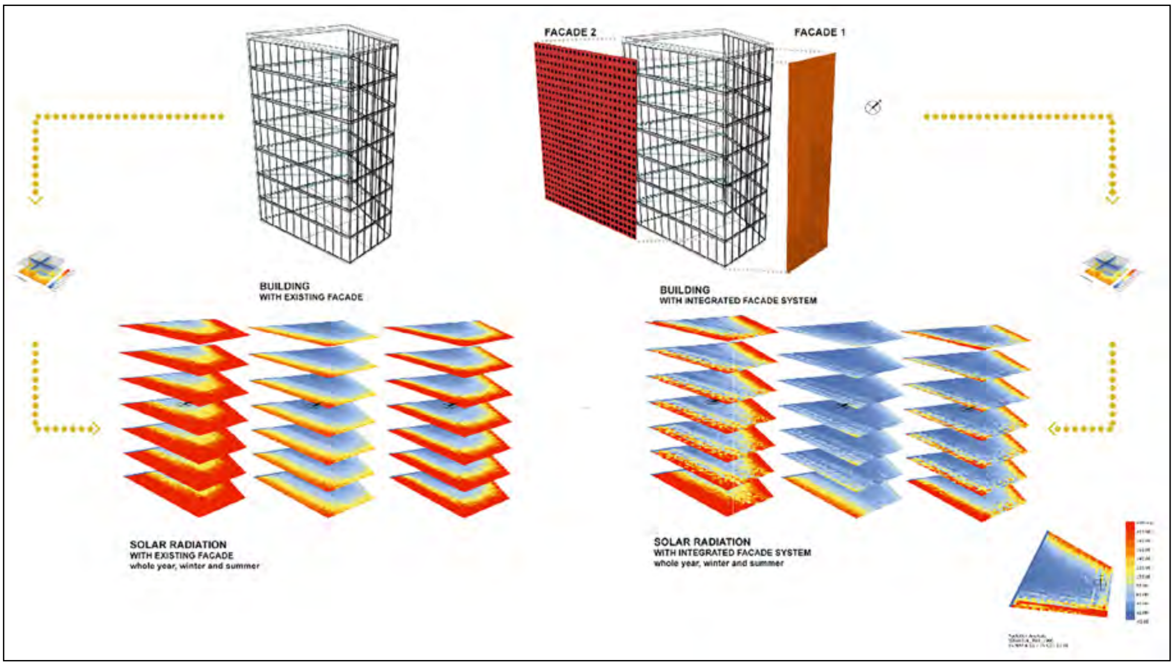


Figure 12. Comparison of solar radiation values for baseline façade and IFS: with the existing façades on the left and with the new developed façades on the right.

inside from the upper gap. As a result of this situation, the last floor has higher solar radiation.

The decrease in solar radiation after using panels can lead to a decrease in the cooling loads during the summer period. However, it also can lead to an increase in the heating load. This study aimed to develop IFS via computational design strategy and investigate it in terms of media display and its effects on solar radiation. So, the effect of IFS on energy consumption can be a subject for future studies. It may be recommended to use IFSs during the summer period and to limit their use in the winter period. In addition, when IFSs are used, they can also be analysed in terms of visual comfort in future studies, as they will also reduce the daylight brightness of the indoor environment.

CONCLUSION

Despite the growing literature on energy-efficiency, interaction, interior comfort, and other related subjects with facades, there are few examples of research that combine the different facades requirements computationally. This paper presents a computational design strategy for IFS, as a sustainable solution for media display and solar shading on building façades. The design framework is developed and tested with the main concerns of two façade types. In detail, it is based on attributes and parameters between data, geometry, and simulation. In particular, the designer is able to use effectively visual output and numerical data from solar radiation analysis. The algorithmic system can adapt to different situations with considerable affordances that guide different project designs rather than a single project. Along with the solar simulation which is included with all-year solar radiation values in this case, daylight, shadow, wind, and precipitation simulations can also be integrated into the algorithm according to the design requirements.

According to hypotheses, results refer to achievement, especially in three sections:

(1) IFS provides an appropriate and practical model for the synthesis of simulation and analysis output data in a wide range of environments since it is a parametric and computational design model.

(2) Multi-functions on the façade can be moderated together with the ease of use of perforated metal panels. However, new material compositions, technical and structural details can offer better solutions. To deepen this research in this direction, an interdisciplinary perspective related to concerns of the façade system should be part of this model.

(3) The shading function of the façade is aided by the simulation of site-specific local climate data in winter and summer periods, and the contextual analysis of the media display allows interaction depending on the resolution.

Regarding the design and renovation process, especially wicked problems requiring adaptive and integrative strategies, the research provided significant correlations between different IFS, and compartments with the baseline structure. As a result, the IFS approach offers higher productivity by decreasing the time spent on developing and testing design alternatives. In particular, one of the most valuable aspects is resilience to the systems when dealing with challenges and adaptation to constantly changing conditions.

Finally, several limitations need to be reconsidered. The scope of the study was limited by computational design and partial mock-up experiments in the early design phase due to the high cost of the LED-integrated perforated panels. Digital fabrication techniques have great potential to improve the integration level of LED and perforated panels. The research has the opportunities of a workshop that was held in university and industry collaboration. Thanks to the collaboration, the interaction of different project groups and a participatory process have been created. However, it is necessary to increase the practical potential of the design idea with the opportunities of fabrication to find consistent solutions to the problem by realising requirements and constraints. The production of a 1:1 prototype can also be seen as an opportunity for the design process and the development of IFS approaches. With the production at 1:1 and experimental study, some details can be evaluated, like panels' distance from the façade, material, thickness, etc. This production can also be integrated with more detailed results of simulations. In future studies, different physical simulation inputs can be added, so that the produced façades can be made more efficient.

Secondly, "the panel" as Euclidian geometry needs to be enhanced to non-Euclidian geometry to overcome the form limitation. Therefore, future research could examine the potential and limitations of non-Euclidian-geometry. For the last limitation, numerous IFS samples are critical to understanding the potential. Research can extend to different dialectics beyond façade applications.

To further our research, the researchers of this study intend to design a new graphical user interface (GUI) to make the system utilised for other stakeholders. Therefore, the GUI is more user-friendly than the visual script-based structure, with high utility in manipulating the design system without specific knowledge. One of the desirable future investigations is to enable interactivity in a panelized media façade by increasing user interaction with any game engine.

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