The Features of the Sustainable Façade Category

N. Rahimi, C. Cucuzzella, and A. Soulikias

***Abstract*—** There is nothing more visible and recognizable among a building's elements than its façade, which serves as the principle communicator of that building's identity and, over time, can even occupy a place in the public's collective memory. The characteristics of any given façade can directly impact the building's surroundings and environment. In recognition of the importance of appropriate façade design and in order to enable a clearer understanding of its elements today, the authors in "The Evolution of the Architectural Façade since 1950: A Contemporary Categorization" categorized different types of contemporary façade design and identified their main features. In this paper, we want to focus on one sub-category among the façade categories defined by Cucuzzella et al.: the Sustainable Façade Category.

In this paper, we wish to describe the characteristics of this façade category and identify the materials and technology employed. We will also present some case studies from this category to help understand the types of features used and their impact over time.

***Key Words*—** Buildings, Environmental Design, Façade Categorization, Sustainable Façade, Sustainability

I. Introduction

Building façades are crucial for energy and environmental efficiency from an engineering perspective. The development of sustainable facades is essential for harmonizing the relationship between humans and nature [1].

According to UN-Habitat information, cities use 78% of the energy worldwide [2], and building contributes about 40% of it. Buildings are an important sector that can reduce energy use and associated emissions, and their most influential part is the façade [3]. There are even more negative impacts of the buildings on the environment, which can be reduced by appropriate changes in façade design. It is sustainable façades that are responsible for minimizing these negative impacts.

Based on the categorization provided by Cucuzzella et al. (2022), a sustainable façade is introduced as a sub-category of the Environmental façade [4], which we will discuss in this paper. This category of facades combines efficiency and moderation with materials, energy, space, and the ecosystem as a whole, with the goal of minimizing negative environmental impacts [5]. Sustainable architecture aims to achieve energy efficiency throughout the lifecycle of a building [4].

The concept of high-performance, sustainable facades refers to exterior enclosures that use as little energy as possible while maintaining a healthy and productive interior environment for building occupants [6]. The role of a sustainable facade is not just to be a barrier between interior and exterior, but it is also a building system which responds to the external environment and significantly impacts the reduction of the building's energy consumption.

II. Methodology

This paper's methodology will be based on the literature review of different studies related to the topic. We will study different types of sustainable façade, then conclude a classification for that. We will also describe each sub-category's characteristics and their effectiveness on interior quality and building energy. The main goal of this paper is to classify and introduce different ways to increase sustainability in building facades. Obviously, there are more ways to do that, but our focus is just on facades.

III. Materials and Techniques

In this part, based on the literature review on different types of sustainable façade, classification of this type is provided, refer to **Error! Reference source not found.**. In this classification, sustainable façade is divided into five main categories: Smart Skin, Kinetic Façades, Vertical Greenery, Solar Façade, and Double Skin Façade. The characteristic of each category and the materials and techniques used on them is described here. Please note that these five categories might not cover all kinds of materials and techniques used in sustainable façade, but these are the most important ones in case of sustainability and building energy saving.

Manuscript received March 27, 2023.

N. Rahimi is a PhD student at Concordia university in faculty of Fine Arts. Individualized Program, Fine Arts Department, Concordia University, Montreal, QC H3G 1M8, Canada

C. Cucuzzella is a professor in faculty of Fine Arts at Concordia university. Department of Design and Computation Arts, Next Generation Cities Institute, Concordia University, Montreal, QC H3G 1M8, Canada

A. Soulikias Rahimi is a PhD student at Concordia university in faculty of Fine Arts. Individualized Program, Fine Arts Department, Concordia University, Montreal, QC H3G 1M8, Canada

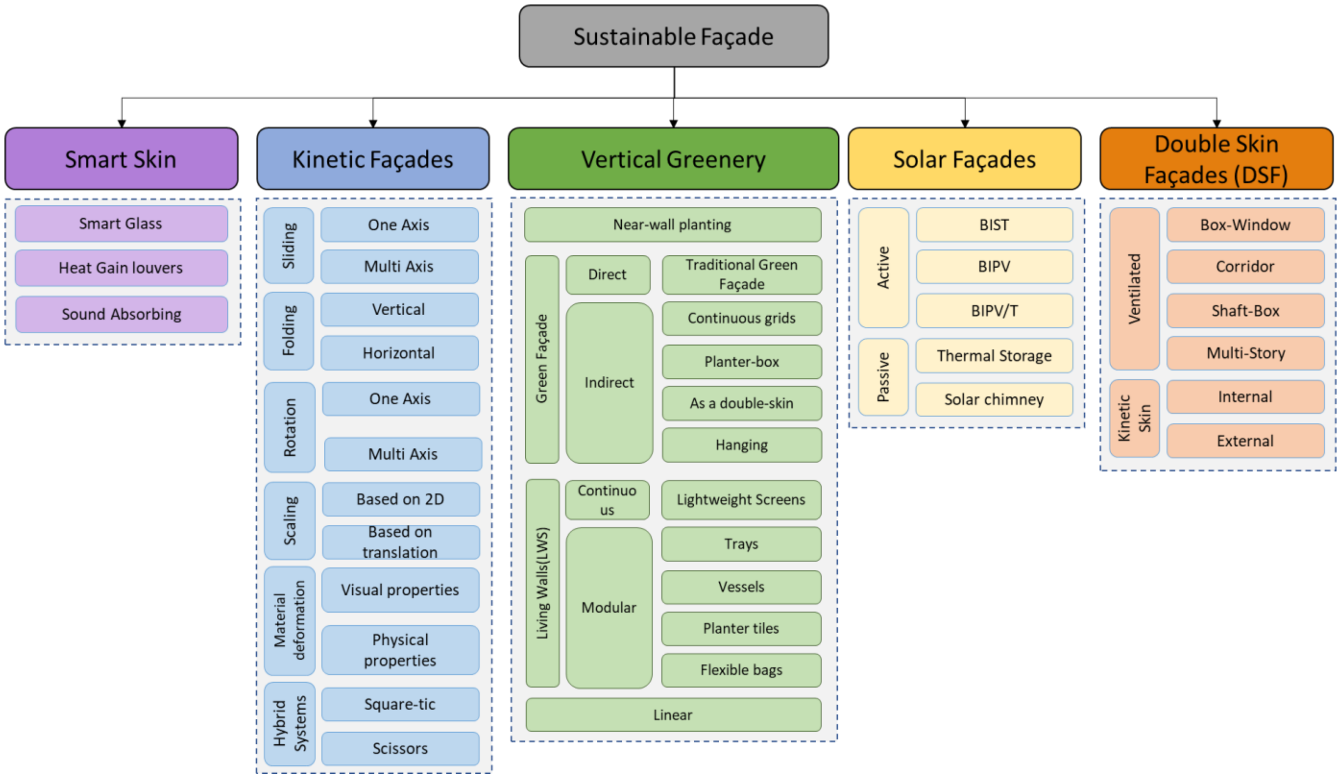

Fig. 1. Categorization of Sustainable Façade

A. Smart Skin

In recent years, smart materials have gained a lot of attention in scientific research, especially in engineering and industrial applications, as well as in architectural applications. The main difference between traditional and smart materials was noted by López et al. (2017) that the former was homogeneous in composition and reacted to external influences, while the latter responds to external stimuli in order to control temperature changes or solar radiation, such as electrochromic glass in curtain walls, windows, shading devices, and more [7]. These three types below are just examples of critical types of smart materials in façades.

1) Daylight Control:

This type is dependent on smart materials, and it controls the brightness level of indoor distribution and glare [8]. Smart Energy Glass (SEG) is a type of smart material that uses a polymer coating placed between two glass layers to change the optical properties when an external voltage is applied [9].

Fig. 2. Three modes of Smart Energy Glass

2) Heat Gain Control

By controlling solar heating in interior spaces, we can increase solar heating during winter and reduce solar gain during summer [10]. When the building façade is covered with heat gain louvers, the inside solar heat gain will be reduced by a management system which is responsible for controlling heat gain, ventilation, and daylighting [11].

3) Noise Control

Sound Absorbing shading devices on a building's façade can provide a better acoustic design for façades [10]. The Sonomorph unit is one of those devices that include an aluminum outer panel and a glass-reinforced plastic inner panel. A net of steel wires is attached to each unit containing the required hardware and sensors [10].

B. Kinetic Façades

A kinetic façade involves the use of geometric transitions to generate movement in space. As a result of this motion or movement, the façade's physical appearance, as well as material properties, change without affecting the building's structure [8]. A kinetic façade maximizes the energy efficiency of buildings while adapting fully to climate change, providing maximum comfort to the occupants [8]. A responsive kinetic façade is the best HPF for improving indoor air quality since it incorporates most of the other facade's advantages, especially its variety of shapes and designs [10].

There are many classifications regarding the Responsive Kinetic Façade types. Moloney (2011) divided geometric transformation systems of kinetic facades into four types [12]:

- Rotation: move around one or more axis.
- Scaling: contraction or expansion
- Translation: movement along with the direction of a vector.
- Material Deformation: Depending on the type of materials, the form can change.

A comprehensive categorization of these types, along with their sub-categories, is proposed according to pattern shape, skin form and façade material, refer to **Error! Reference source not found.**.

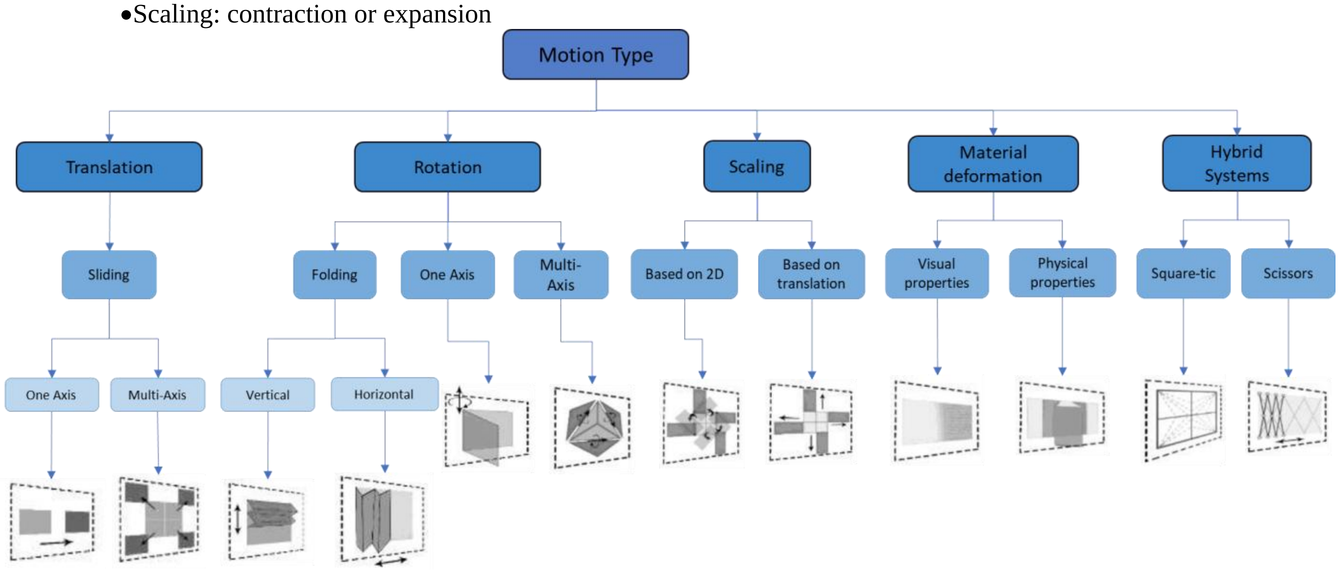

Fig.3. Categorization of Kinetic Façades Based on Their Pattern Shape, Skin Form and Façade Material [5].

C. Vertical Greenery

Urbanization and population growth have reduced the amount of green space in cities, affecting some of the city's livability. Another consequence of urbanization is the increase in heat generated from cities, known as urban heat islands (UHI). A vertical greenery system (VGS) can be used to retrofit passive cooling to an existing building when installing other heating and cooling options is too expensive and time-consuming [13].

Typically, traditional green facades are made from creeping plants that climb up a building's façade with the support of its wall material. A simple support system attachable to the wall is usually used to support climbing plants in these systems [14]. Vertical greenery on a building can be green plants on facades or farming plants can be used. In this part, our focus is just on typical greenery, not farming on facades.

The impact of greenery on the façade on the energy efficiency of the building is considerable. Köhler's study (2008) of a traditional green façade in Berlin showed that Ivy green facades (Hereda helix) could produce temperature differences up to 3 ̊C on cold winter nights (insulation effect) and 3 ̊C in summer (thermal resistance) [15]

Vertical greenery systems can be divided into four categories: Near-Wall Planting, Green Façade (GF), Living Wall Systems (LWS), and linear greenery, refer to **Error! Reference source not found.**. These categories differ primarily in their root systems, plant species, irrigation systems, and the space between vegetation and façades [16]. Green Façade also divided into two categories: direct and indirect. In direct façades, plants adhere directly to the surface of the wall, but in indirect façades, the vegetation layer is supported by a supporting structure [16].

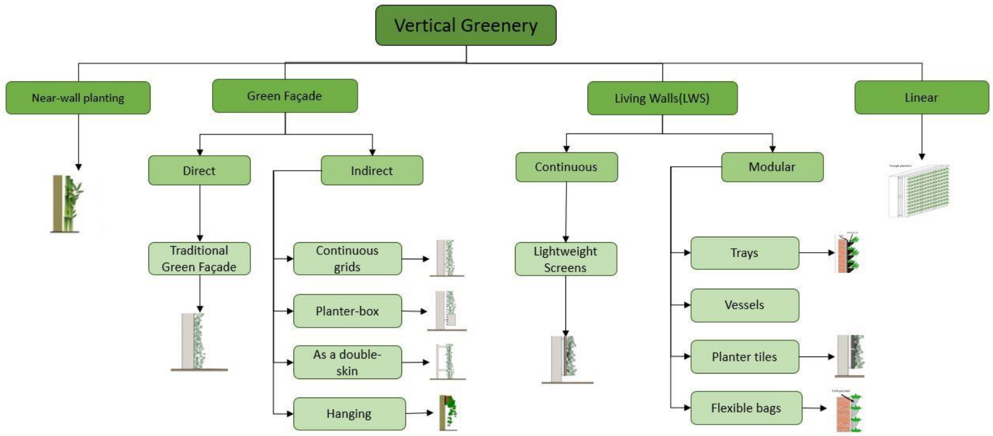

Figure 4. classification of green walls, according to their construction characteristics [13], [16]

D. Solar Façades

The sun provides an abundance of energy to the earth, so it is essential to take into account how sunlight impacts facades. Researchers are focusing on ways to manage sunlight in buildings, and properly designed facades can work as a bridge between the built and natural environments [6]. Building facades can be divided into two parts based on their engineering and Design: solids and voids [18]. Solid structural elements, such as solid walls, for instance, are thick, heavy, stable, and visually opaque, while void structural elements, such as glass, windows, and doors, are lightweight and visually transparent [18]. Due to the solid and void components of building facades, solar facades can be categorized into two types: opaque and semi-transparent. A categorization of these types, along with their sub-categories, is proposed (**Error! Reference source not found.**).

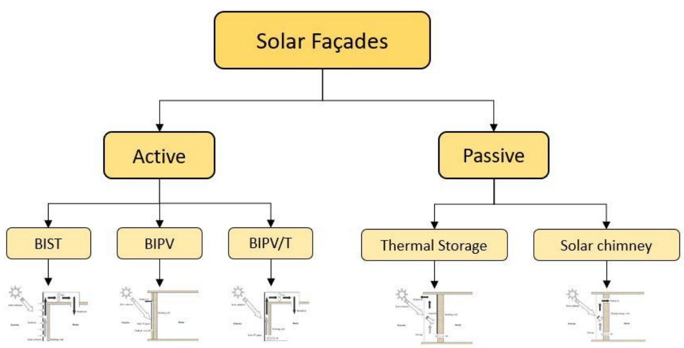

Figure 5. classification of solar façades [4], [18].

E. Double Skin Façades (DSF)

Adapting the thermal properties of buildings with multi-skin ventilated facades with integrated building elements that respond to climatic conditions (automatic shading and automatic opening) can result in improved annual energy savings [19]. Double skin façade (DSF) was first introduced by Le Corbusier in the early 1900s [20].

A double-skin façade consists of three skins: an external skin (usually glass), an intermediate space and an internal skin (also usually glass) [21]. By evacuating solar radiation absorbed through the glazing envelope, the DSF concept enhances ventilation within the building [22]. Therefore, the energy consumption of cooling and heating demand will be minimized.

The ventilated façade is most suitable in climates with hot summers and orientations that receive direct sunlight. This heat dissipation through the ventilated chamber represents a significant energy saving for air conditioning systems under these conditions, as solar radiation can raise the surface temperature by 60 degrees Celsius [20]. It is possible, in certain cases and only during cold periods, to introduce heated air from the cavity into the building in order to reduce heat losses caused by ventilation [20].

The addition of the conventional system to the building envelope can improve the energy and comfort performance of the building. In warm months, building envelopes can reduce energy losses, while energy gains can be dramatically increased in cold months, and the building's indoor temperature can decrease (summer season) or increase (winter season) in comparison to conventional systems [20]. Different types of DSF are illustrated in **Error! Reference source not found.**.

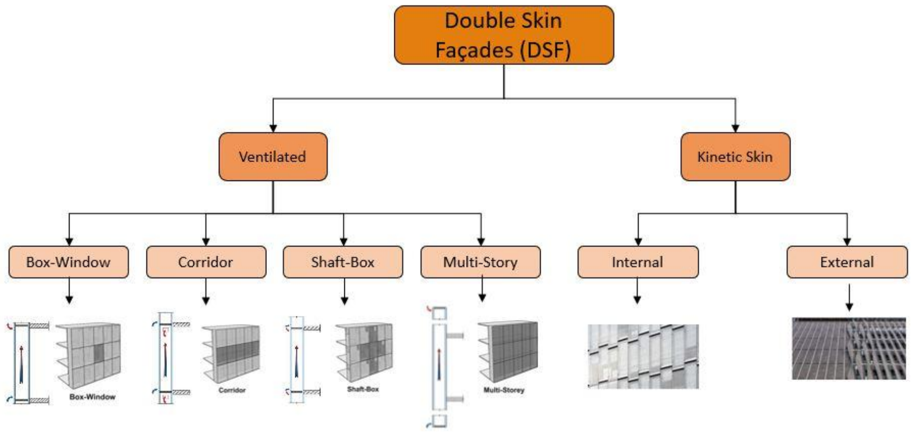

Figure 6. Classification of DSF

IV. Conclusion

To solve practical problems in building designs and support robust decision-making, sustainable Design requires not only interdisciplinary knowledge but also the application of multidisciplinary tools and techniques. The research presented in this article aimed to gather information about all kinds of sustainability in façades, categorize them and provide technical details for each of them. Furthermore, the impact of each category on the energy efficiency of the building was discussed.

In general, the use of all these types of sustainable façade can be beneficial for the thermal comfort and energy efficiency of the building. Furthermore, it can reduce the negative impact on the environment, and third, in some cases, increase livability in the city.

Acknowledgement

The authors would like to acknowledge Concordia University for funding and support towards this research.

References

[1] C. Cucuzzella, N. Rahimi, and A. Soulikias, "The Evolution of the Architectural Façade since 1950 : A Contemporary Categorization," pp. 1–32, 2022. https://doi.org/10.3390/architecture3010001
[2] United Nations, "Climate Action." https://www.un.org/sustainabledevelopment/climate-change/
[3] S. Sarihi, F. Mehdizadeh Saradj, and M. Faizi, "A Critical Review of Façade Retrofit Measures for Minimizing Heating and Cooling Demand in Existing Buildings," Sustain. Cities Soc., vol. 64, no. October 2020, p. 102525, 2021, doi: 10.1016/j.scs.2020.102525. https://doi.org/10.1016/j.scs.2020.102525
[4] C. M. Lai and S. Hokoi, "Solar façades: A review," *Build. Environ.*, vol. 91, pp. 152–165, 2015, doi: 10.1016/j.buildenv.2015.01.007. https://doi.org/10.1016/j.buildenv.2015.01.007
[5] H. S. M. Shahin, "Adaptive building envelopes of multistory buildings as an example of high performance building skins," *Alexandria Eng. J.*, vol. 58, no. 1, pp. 345–352, 2019, doi: 10.1016/j.aej.2018.11.013. https://doi.org/10.1016/j.aej.2018.11.013
[6] A. Aksamija, "Design methods for sustainable, high-performance building facades," *Adv. Build. Energy Res.*, vol. 10, no. 2, pp. 240–262, 2016, doi: 10.1080/17512549.2015.1083885. https://doi.org/10.1080/17512549.2015.1083885
[7] B. Nashaat and A. Waseef, "Responsive Kinetic Facades: An Effective Solution for Enhancing Indoor Environmental Quality in Buildings," *First Memaryat Int. Conf. (MIC 2017) Archit. Futur. Challenges Visions*, no. April, pp. 0–13, 2017.
[8] J. Ahmad and H. Z. Alibaba, "KINETIC FAÇADE AS A TOOL FOR ENERGY EFFICIENCY," no. December, 2019.
[9] M. López, R. Rubio, S. Martín, and Ben Croxford, "How plants inspire façades. From plants to architecture: Biomimetic principles for the development of adaptive architectural envelopes," *Renew. Sustain. Energy Rev.*, vol. 67, pp. 692–703, 2017, doi: 10.1016/j.rser.2016.09.018. https://doi.org/10.1016/j.rser.2016.09.018
[10] C. I. Seyrek, B. Widera, and A. Woźniczka, "Sustainability-related parameters and decision support tools for kinetic green façades," *Sustain.*, vol. 13, no. 18, pp. 1–16, 2021, doi: 10.3390/su131810313. https://doi.org/10.3390/su131810313
[11] G. Pérez, J. Coma, I. Martorell, and L. F. Cabeza, "Vertical Greenery Systems (VGS) for energy saving in buildings: A review," *Renew. Sustain. Energy Rev.*, vol. 39, no. January 2015, pp. 139–165, 2014, doi: 10.1016/j.rser.2014.07.055. https://doi.org/10.1016/j.rser.2014.07.055
[12] M. Köhler, "Green facades-a view back and some visions," *Urban Ecosyst.*, vol. 11, no. 4, pp. 423–436, 2008, doi: 10.1007/s11252-008-0063-x. https://doi.org/10.1007/s11252-008-0063-x
[13] R. C. G. M. Loonen, M. Trcka, D. Cóstola, and J. L. M. Hensen, "Performance simulation of climate adaptive building shells-Smart Energy Glass as a case study," *Proc. SSB*, no. December 2016, pp. 1–19, 2010, [Online]. Available: http://www.bwk.tue.nl/bps/Hensen/publications/10_ssb_loonen.pdf
[14] M. Kanaani and D. Kopec, "The routledge companion for architecture design and practice: Established and emerging trends," *Routledge Companion Archit. Des. Pract. Establ. Emerg. Trends*, pp. 1–580, 2015, doi: 10.4324/9781315775869. https://doi.org/10.4324/9781315775869
[15] J. Moloney, Designing kinetics for architectural facades: State change. 2011. doi: 10.4324/9780203814703. https://doi.org/10.4324/9780203814703
[16] R. A. Bustami, M. Belusko, J. Ward, and S. Beecham, "Vertical greenery systems: A systematic review of research trends," *Build. Environ.*, vol. 146, no. August, pp. 226–237, 2018, doi: 10.1016/j.buildenv.2018.09.045. https://doi.org/10.1016/j.buildenv.2018.09.045
[17] S. Peyman, "Data modeling and simulation approaches for Urban Greenery Systems in the context of climate change," no. March, 2022, [Online]. Available: https://spectrum.library.concordia.ca/id/eprint/990496/%0Ahttps://spectrum.library.concordia.ca/id/eprint/990496/1/Peyman_MASc_S2022.pdf

[18] M. Manso and J. Castro-Gomes, "Green wall systems: A review of their characteristics," Renew. Sustain. Energy Rev., vol. 41, no. January 2018, pp. 863-871, 2015, doi: 10.1016/j.rser.2014.07.203. https://doi.org/10.1016/j.rser.2014.07.203

[19] G. Quesada, D. Rousse, Y. Dutil, M. Badache, and S. Hallé, "A comprehensive review of solar facades. Opaque solar facades," *Renew. Sustain. Energy Rev.*, vol. 16, no. 5, pp. 2820–2832, 2012, doi: 10.1016/j.rser.2012.01.078. https://doi.org/10.1016/j.rser.2012.01.078

[20] D. Andreeva, D. Nemova, and E. Kotov, "Multi-Skin Adaptive Ventilated Facade: A Review," *Energies*, vol. 15, no. 9, 2022, doi: 10.3390/en15093447. https://doi.org/10.3390/en15093447

[21] J. Santa Cruz Astorqui and C. Porras-Amores, "Ventilated Façade with double chamber and flow control device," *Energy Build.*, vol. 149, pp. 471–482, 2017, doi: 10.1016/j.enbuild.2017.04.063. https://doi.org/10.1016/j.enbuild.2017.04.063

[22] M. M. S. Ahmed, A. K. Abel-rahman, A. H. H. Ali, and M. Suzuki, "Double Skin Faç ade : The State of Art on Building Energy Efficiency," vol. 4, no. 1, 2016, doi: 10.7763/JOCET.2016.V4.258. https://doi.org/10.7763/JOCET.2016.V4.258

[23] J. Zhou and Y. Chen, "A review on applying ventilated double-skin facade to buildings in hot-summer and cold-winter zone in China," *Renew. Sustain. Energy Rev.*, vol. 14, no. 4, pp. 1321–1328, 2010, doi: 10.1016/j.rser.2009.11.017. https://doi.org/10.1016/j.rser.2009.11.017

AUTHORS' BIBLIOGRAPHIES

Negarsadat Rahimi is an architect and interior designer. She is a PhD student at Concordia University, Montreal, in the Individualized Program (INDI), under the supervision of Dr. Carmela Cucuzzella, Dr. Ursula Eicker, and Dr. Hua Ge, pursuing an interdisciplinary research-creation study with the title: Understanding the Façade Retrofitting by Minimizing Heating and Cooling Demand while Considering the Impact of Façade Design on Sustainability and Livability of the City. Her study aims to evaluate the importance of the façade design in the case of building energy and urban development. Her focus is on developing a catalogue for façade systems in buildings and façade retrofitting based on the energy simulation of the building and its needs.

She holds a B.Arch in interior architecture from Sooreh University, Tehran, Iran, an MA in architectural technology from Pars University of Art and Architecture, Tehran, Iran. She has been working as a research assistant at the Next Generation Cities Institute (NGCI) and In¬tegrated Design And Sustainability for the Built Environment (IDEAS-BE) in Montreal, Canada, since 2021.

Dr. Carmela Cucuzzella is a Professor in the Design and Computation Arts department, at Concordia University. She is founding co-director of the Next Generation Cities Institute (NGCI) at Concordia Univerisity. She holds the University Research Chair in In¬tegrated Design And Sustainability for the Built Environment (IDEAS-BE). Her current research focuses on the didactic phenomena of eco- art, architecture and design in the city as a means for raising awareness and mobilizing sustainable action.

Among many other peer-reviewed publications, she has recently published four books: (1) in 2022, she co-edited with Jean-Pierre Chupin and Georges Adamczyk, The Rise of Awards in Architecture. (2) In 2021 she co-wrote with Jean-Pierre Chupin Emmanuel Rondia and Sherif Goubran the open-access book, Reimagining Waiting for the Bus: Design Principles for Spaces Surrounding Bus Shelters, a creative guide, which is the result of an international competition, provides a synthesis of the best ideas in the form of a free resource aimed at stimulating citizen discussion and community group engagement around the improvement of small urban environments connected to bus stops. (3) in 2020 as a sole author, Analyzing Eco-architecture Beyond Performance offers an overview of the state of the field and constitutes a critical introduction to the study of environmentalism in architecture. Contrary to the technological and performative biases of most eco-design studies, the book helps to understand how meaning is embedded in all types of eco-architecture. (4) in 2020, she co-edited with Dr. Sherif Goubran, Sustainable Architecture between Measurement and Meaning takes the reader on a journey that distances itself from the mainstream approaches for sustainable architecture.

Aristofanis Soulikias is an architect and film animator. He is a PhD student at Concordia University, Montreal, in the Individualized Program (INDI), under the supervision of Dr. Carmela Cucuzzella, Dr. David Howes, and Prof. Luigi Allemano, pursuing an interdisciplinary research-creation study with the title: Sensing the city: revealing urban realities and potentials through handmade film animation, which aims at evaluating the tactile qualities of filmmaking with regard to the haptic but also temporal nature of the city, given the increasing presence of stop-motion techniques due largely to adapted digital technologies.

He holds a B.Sc and a B.Arch from McGill University, an MA in Building Conservation from the University of York, UK, and a BFA (Major in Film Animation) with Distinction from Concordia's Mel Hoppenheim School of Cinema. His graduation film, Last Dance on the Main, was selected by TIFF's Canada's Top Ten for the year 2014. In 2019 he was the recipient of the Jorisch Family Artist Residency in Salzburg, Austria. His research is supported by the Social Sciences and Humanities Research Council of Canada, and he is amongst Concordia's Public Scholars for the 2022-2023 academic year.