Exploration of the Greening Interventions on the Façade of the Peculiar Boarding House for the Enhancement of the Comfort within the Residence and the Urban Environment

Tianyu Zhao, Xiaonan Li

Abstract**—**Large number of existing buildings, especially those built in the last century, have become abandoned due to the discrepancy between their material and function life span. The discrepancy, in meantime, provides the existing buildings with new opportunities in society, economic, culture and art aspects. Under the vision of carbon-neutral, the adaptive reuse of existing buildings greatly reduces the material consumption in community build-up and development, while integrating the concept of reuse and reactivation into people's daily life. More possibilities of green intervention methods have been promoted and tested around the world to enhance the performance of the reused buildings to reach lower energy consumption and higher comfort. The research discusses vertical greenery intervention’s potential in the context of Pécs, Hungary, which contributes to the adaptive regeneration of the city as a carbon-neutral and resident-friendly tool, as well as a transit of future development of Pécs. The paper focuses on its green intervention on the existing building's envelope, which serves both insulation/protection to the building and living wall of the adjacent public open space. The positive impact of green intervention to existing buildings and the subsequent construction of livable and comfortable adjacent buildings is therefore discussed.

Keywords**—**Green intervention, vertical greenery, panel house, urban regeneration, ENVIMET

I. Introduction

In 2020, approximately 60% of the global population are living in urban areas, a third in metropolitan cities. By 2035, it is predicted that the metropolitan population will reach 39%. The urbanization has been proceeding rapidly in the globe, and a foreseeable future is that it will keep processing with more advanced and sustainable strategy. (United Nations Human Settlements Programme, 2020).

The unstoppable forces of urbanisation are depleting large amounts of natural vegetation and replacing it with concrete buildings and low albedo surfaces. These resulting changes in the thermal performance of surface materials and the lack of evapotranspiration in urban areas have led to a phenomenon known as the Urban Heat Island (UHI) effect, and the sustainable cities of the future will require a process of urban environmental reshaping.

Vertical greenery especially building façade and wall greenery, gained significant recognition more than ever; it is becoming one of the vital design elements of dealing with global sustainable architecture and diverse development [1]. Urban Green Infrastructure (UGI) allows vegetation to be brought into the urban environment and are a very promising passive sustainable technology for improving the energy performance of new and existing buildings [2] [3] [4].

Vertical greenery especially building façade and wall greenery, gained significant recognition more than ever; it is becoming one of the vital design elements of dealing with global sustainable architecture and diverse development [1]. The mainstream and general aspect of vertical greenery include multiple aspects, which include climate, energy, aesthetic, culture, social issue and economy. From the macro and microclimate and living environment point of view, buildings' facade greenery is one of the most effective means of increasing urban green mass and carbon absorption, it is capable to generate considerable protection and quality condition to its adjacent microclimate (building interior and adjoining public open space) [5], nevertheless, it serves as an effective media to assure the urban biodiversity of the locality [6]. From the energy point of view, a scientifically planned green envelope of buildings can effectively reduce the interior heating or cooling demand, and this effect shows more significantly in mid-to-high latitude cities. Aesthetic, culture and other social issues are joined with each other. An increasing number of nature-philic aesthetic pieces have jumped into the public vision since the 20th century has driven and congregated, with the human nature of easy-going with green and nature, the application and position of greenery in both visual and social comfort.

On a building scale, green roofs and Vertical Greenery on Facades (VGF) help to promote energy efficiency, grey water treatment, reduction of sound transmission and extension of the envelope. Through envelope protection and shading, greening systems are able to reduce the surface temperature of buildings during warm periods [7]. Among the impacts generated by green façades, the impact on the energy behaviour of buildings

Tianyu Zhao, Hubei University of Technology, China,
Xiaonan Li, University of Pécs, Hungary

deserves special attention given the high environmental impact of buildings. Green façades can be an effective passive strategy for controlling heat transfer through the building envelope and reducing the building's energy demand for air conditioning. [8] [9] [10]. Research work is needed to broaden the knowledge of cooling and heating energy savings achieved through green facades in order to better assess their practical benefits. VGF offers greater application possibilities due to the wider vertical surfaces of buildings in cities [11].

VGF comprises two main categories: green facades (GF) and living walls (LW). GF can be implemented in direct or indirect type or in double skin form. The plants can be evergreen or deciduous, climbing or cascading, placed at the base of the façade or at different heights along it, directly attached to the wall in the direct type and directly attached to vertical supports in the indirect type. In double-layered GF, the greenery is placed at a certain distance from the enclosure, forming an air gap that affects the thermal performance of the system. LW are characteristically more complex than GF, as they include the support structure, the plants, the growing medium and the irrigation system. LW can be continuous or modular. Continuous LWs are achieved by means of a frame fixed to the wall and panels that hold the plant growth. A modular LW consists of several interconnected elements, such as containers, pots or flexible bags. The GF can therefore be used in a wider range of applications than the LW due to its simpler design, ease of installation and maintenance and lower costs [12] [13].

There are commonalities in aesthetics and human communication. Whether it be the aesthetics of reverence for closeness to nature that has increasingly entered the public view since the 20th century, or the human’s natural affinity for nature and greenery, and the increased demand and awareness for greener, healthier cities, which have accelerated and consolidated the use and position of greenery in terms of visual comfort and social amenity.

While innovative new buildings are constantly being created, the city's stock of buildings, streets and open public spaces are important subjects that cannot be ignored on the road to sustainability. At the same time, however, they are also a material and cultural asset. There are numerous historical examples, such as the use of the Louvre, which no longer has a practical function, as a national museum, while the modern concept of adaptive use and renewal of stock buildings dates back to the 1970s. On the opposite side of the building stock are the existing streets and urban public spaces. With the further pursuit of urban living environments (in terms of sociability, walkability, convenience, circulation, comfort and aesthetics), scholars in several countries have assessed and problematised urban public spaces everywhere. Whereas deficiencies in humaneness, social friendliness, proximity to nature and aesthetics are common among many very large, large and medium scale cities.

In recent years, the renewal of existing buildings and places has seen an increase in the intervention of greenery based on the integration of functional spaces and facades. In addition to spatial and vertical greening installations, more and more façade regeneration chooses to apply different types of vertical greening to achieve multiple aesthetic and practical effects. It is not only an effective way to revitalise the skin of the building being regenerated and optimise its performance, but also makes an important contribution to the quality of the adjacent streets and public spaces.

The façades of existing buildings are the most valuable existing vertical cut-off resource, both for the internal environment of the building and for the quality of the adjacent urban public space. Examples of practice include

The city of Pécs, one of Hungary's major international talent cities, has a growing demand for a pleasant, attractive and naturally appropriate public space atmosphere, both in terms of the development of new carbon-neutral neighbourhoods, replicated concrete slab neighbourhoods that have developed over the last hundred years, and the historical and cultural concentration of the old town. In this paper, we examine the revitalisation of greening interventions on existing building facades through the lens of urban public space, and consider how vertical greening interventions, in addition to the revitalisation and renewal of the buildings themselves, can enhance the public space directly related to them, in order to consider and make recommendations for the optimisation of urban regeneration and the construction of a carbon-neutral city in the urban context of Pécs.

II. METHODOLOGY

The research rises from an urban public open space perspective, aims to discuss the potential and capability of vertical greenery on building facades and produces the fundamental study for the green development of the existing city fabric of Pécs. The research sets its base on the literature review, in-situ observation and ENVIMET simulation, where literature review covers three topics: international prosperous case study examples, theoretical categorizations of vertical greenery applications, Hungarian panel house and the theoretical and practical state of vertical greenery on building facade in the Hungarian context, and ENVIMET simulation provides visual comparisons regarding panel houses’ exterior environment comfort (Fig. 1). With the help of in-situ observation, the authors have collected different data including photograph documentation, facade typology and mapping of panel house estates in Pécs. The analysis was based on the coupling of the existing international theory achievements of vertical greenery and the existing building facades of city Pécs. Whereas, the coupling was based on interior comfort and exterior comfort.

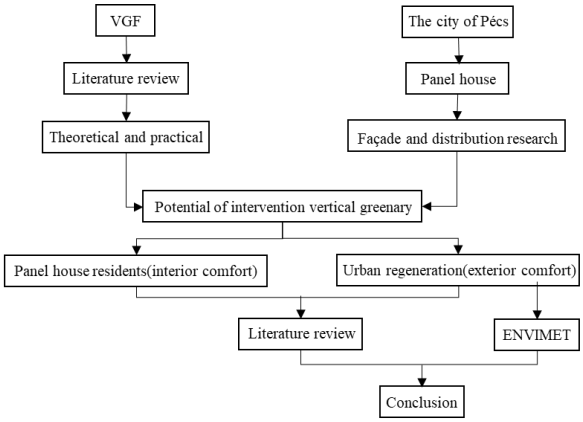

Fig 1: Methodology of the research

III. Panel house as a widely applied residential building form in Pécs

A. Buildings in Pécs

The city of Pécs is a mid-to-large scaled township located in southern Hungary. Its thriving history traced back to the early Roman time. Through the thousands of years of evolution, a few architecture and street typologies exist between the medieval city wall (contour of the historical downtown) and the city outskirt. The scale of streets and squares within the medieval city wall was kept. Except for the heritage buildings from the early Christian time the Turkish Empire time, structures inside the medieval city wall are composed of traditional multi-storey buildings similar to the Central European style with hundreds of years' history, restored buildings and new buildings designed in a way that fits into the existing tone of the district. Outside the medieval city wall, there are four dominant types of buildings; first, 3-4 storey high brick houses (apartment building or business-residential combined), second, 4- 6 or 11 storey high panel houses, third, single-family houses, and fourth, a series of cultural buildings constructed around 2010 when Pécs won the European Cultural Capital. They are connected to their adjoining streets and public open spaces with respective characters. Brick houses of 3-4 storeys form row houses that directly connect to the pedestrian passage of the street, it is observed that no or limited greenery exists in between. Several panel houses form the apartment estate and exist in groups or clustered. Some of them are connected directly to the pedestrian passage of the main street, while others lay in a street block in a free-standing manner with a few garden infrastructures co-existing. Single-family houses are either free-standing on the plot keeping a buffer garden from the street or aligned directly with the street elevation with no setback connected front facades. However, New cultural buildings keep a well-planned front or side green open space from the pedestrian passage.

B. Panel House

Panel house is an apartment construction system imported from the Soviets in the 1920s [14]. It reached its peak between the 1950s-1980s. In the city of Pécs, the land of Hungary, and even in Central European countries, panel house occupies a considerable ratio of residential building stock [15]. As a type of precast apartment building, panel houses are designed with a few generations of construction systems and morphology. They are constructed with concrete-insulation composite panels and have a relatively fixed apartment layout. Therefore, compare to the conventional 3-4 storey brick houses, panel houses are more efficient in planning and construction, which fit the Hungarian national condition and the housing demand at that time.

The panel houses can be divided into a multi-storey apartment building and high-rise apartment building according to the height; while concerning the building composition, there are building with single staircase, double staircase and triple staircase compositions. Observation of the research shows that the facades of panel houses in the same area tend to be plastered with similar colours or compositions. Concerning the form of openings, living rooms and bedrooms usually have double-hinged windows, and balconies can be categorized into three types: open corridor, 3-side small open balcony for a single room, semi-open balcony for living room. The diversity of balcony forms provide more collaboration possibilities for vertical greenery intervention to panel house facades.

Base on the study of panel house facade models in Pécs (Fig. 2) the opening ratio (gross window and balcony area per gross facade area) can be carried out. The result shows that multi-storey panel houses have an opening ratio (35%-47%), and for high-rise panel houses the ratio is (22%-30%) (Table 1). The rest part is plaster surface and, if applicable, other surfaces for the ground floor. The plastered part is precast concrete panels with integrated thermal insulation. In accordance with the year of construction, different panel systems were applied, where the thickness of wall composition ranges from 19-27 cm [15]. It can also be calculated that the area ratio for the potential of vertical green intervention is (53%-78%).

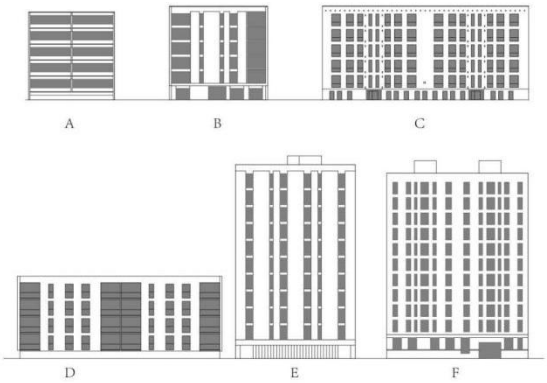

Fig 2: Panel house model facades in Pécs (Illustrated by authors)

TABLE I
PANEL BUILDING SOLID AND OPENING RATIO

	Opening Ratio	Solid Ratio	Type
A	43%	57%	Multi-Storey
B	47%	53%	Multi-Storey
C	35%	65%	Multi-Storey
D	46%	54%	Multi-Storey
E	22%	78%	High-rise
F	30%	70%	High-rise

IV. The Role of the Green Façade

A. Benefits or functions

Vertical greenery is generally defined as the greenery on the vertical faces of buildings or other installations with vegetation material. The paper focuses on the vertical greenery on the building facade (VGF). Researchers worldwide have categorized the urban vertical greenery on building facades with a different focus and for different purposes, which can be generally sorted into techniques of installation, function, vegetation typology application and aesthetics.

B. Technique of Installation

The vertical greenery applied on the building facade is generally distinguished as facade greenery (FG) and living wall (LW), based on the collaboration method of vegetation and facade. Haukun Lin and more researchers produced a more detailed category, in which FG is further sorted as direct, indirect and indirect at a transitional space according to the actual mean of attaching to the facade wall. The main character of which is that the growth of vegetation is supported by the structure installed on the facade wall while rooting in a container installed at the bottom. Accordingly, the applied vegetation is dominated by the creeper plants. On the other hand, LW is sorted as soil container system, substrate module system and felt system in accordance with the attaching method to the facade wall. The main character of which is a much closer collaboration between the greenery and the facade wall, because the roots of vegetation are attached to the wall in a surface manner, thus there is a wider choice of applied vegetation than FG [16]. Similarly, other researchers Lin, Xiao, Lu, & Musso categorized the vertical greenery on facades into cable wire system, wire mesh system and pocket system, where the first two types belong to FG, while the third type belongs to LW [17]. However, Susan Loh categorized FG’s construction into modular trellis panel system, modular trellis, grid system and wire-rope net system [18].

C. Function

Vertical greenery on building facades (VGF) has proved to have multi-beneficial to urban enrichment and the building itself (Table 2). The multiple benefits by VGF are listed in table 2 with different categories. The commonly analyzed functions are related to the thermal performance of the building [19], air quality, microclimate, urban heat island [20], urban biodiversity [21]and ease of noise and light pollution [22].From an aesthetic point of view, besides the visual quality of new facades, vertical greenery intervention is also introduced to fix the visual blemishes on existing facades, and thus regenerate the performance facades [23] [21]. Meantime, the social value of VGF has also been proved, The application of VGF has an indirect effect on social safety by reducing violence and crime [17]. Meanwhile, several papers demonstrated that both FG and LW have a positive impact on easing stress and raising work efficiency, which is an advantage to people’s physical and mental health [24].

TABLE II
The Multiple Benefits of VGF

Author(s)	Opinion(s)	Categories
Abdollah Baghaei Daemei, et al.	1. VGS have considerable effect on reducing nearby temperatures (range between 0.32 °C and 0.75 °C). 2. Temperature increases at farther distances from the VGS. 3. VGS improves microclimatic condition through a thin layer of air among the leaves which increases the temperature near the wall. 4. VGS can create better situations by reducing the temperature in the summer time, increasing temperature in the winter time, and providing more outdoor thermal comfort.	Greenery and thermal comfort
Tobi Eniolu Morakinyo, et al. [25]	1. Facade greening is beneficial for daytime urban cooling and heat island mitigation. 2. The degree of cooling benefit is mostly dependent on greened facade ratio (GFR). 3. For a high-density Hong Kong, ∼1 °C temperature drop requires 30–50% GFR.	Greenery and thermal comfort
Hayder Alsaad, et al. [26]	1. The living wall resulted in a slight reduction of outdoor air temperature. 2. Facade greening reduced outdoor MRT (mean radiant temperature) and indoor temperature significantly. 3. Facade greening presents a good potential to combat the effects of heatwaves.	Greenery and thermal comfort
Dongjin Cui, et al. [27]	1. Centralized façade greening within 3 m from the ground has the greatest thermal benefit at pedestrian level. 2. Façade greening has negligible effect of improving pedestrian air quality.	Greenery and thermal comfort Pavement comfort
Negar Mohammadzadeh, et al. [28]	1. Outdoor thermal comfort is positively associated with outdoor acoustic comfort	Outdoor environmental comfort indicators
Rui Sun, et al. [29]	1. Ourdoor comfort considerably depends on wind speed and solar radiation. 2. Building form and oriantation can contribute to the optimization of wind speed and solar radiation at the adjacent environment. 3. The optimization design depends on the climate characteristics of the region.	Outdoor environmental comfort indicators
Luigi Schibuola, et al. [30]	1. To improve pedestrian comfort, the best technology for the building envelope is resulted the introduction of vertical greenery. 2. The benefits also include storm water capture and air quality improvement.	Pavement comfort
Ratih Widiastuti, et al. [31]	1. Bare wall has higher temperature than green facade. 2. Temperature decrease was more visible from 1.8 °C to 7.8 °C when building facade covered by greater vegetation.	Indoor thermal comfort

Nyuk Hien Wong, et al. [32]	1. the effect of the vertical greening system on the ambient temperature was found to be dependent on the particular vertical greening system. vgs 2 had almost no effect on the ambient temperature, while the effect of vgs 4 was felt at a distance of 0.60 m. 2. The physical structure, material and size of the panels carrying the substrate and plant species, the type of substrate, composition, depth and moisture content, all influence the various properties of the vertical greening system.	Surface temperature
A. De Bock, et al. [33]	1. LAI is considered to be a key performance indicator for vertical greening	Outdoor environmental comfort indicators
Timothy Van Renterghem, et al. [34]	1. Noise reduction is one of the multiple benefits of greening measures for the building envelope	Outdoor environmental comfort indicators
Samar Sheweka, et al. [35]	1.Problems like the Heat Island Effect, Global Warming, CO2 reduction in cities are all addressed by Green Roofs and Walls.	Outdoor environmental comfort indicators

V. Simulation of Outdoor Thermal Comfort by Analysis Diagram

The authors selected a representative group of 10-storey panel houses to be simulated based on their distribution and street environment in Pécs. The group of buildings was simulated respectively in their current state (with exposed external surfaces of 27cm insulated concrete composite walls) and intervened by mixed substrate greenery (LW). External air temperature data at pedestrian height and top level height were extracted and presented through the Leonardo component of ENVIMET (Fig. 3). In late July 2022, the maximum temperature in the city of Pécs exceeded 40℃, and late June 2021 in other parts of Hungary. These peak temperature haven’t been recorded in the past 120 years [36]. Based on the temperature history of the city of Pécs in 2021 and2022 [37], the authors chose the temperature data on 23 July 2022 and picked the peak point at 15:00 as the basis for the summer simulation. The simulations were conducted with a day-round temperature ranging from 22.78℃to 37.22℃. It can be seen that without intervened greenery, external air temperatures at pedestrian level (175 centimeter height) ranges from 34.28℃ to 35.90℃ within 10 metres from the panel houses, with a monotone increasing trend as being farther from the building towards the main street. In the simulation at 35 metres high (top level), the external air temperature decreases with distance and the air temperature at the building perimeter within 10 metres can reach 34.31℃ with a minimum of 34.16℃ and the facing sides of the two panel houses are the temperature peak point.

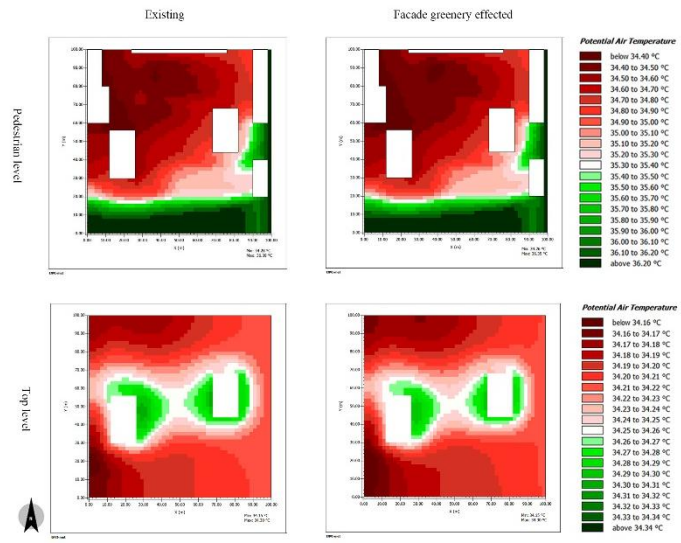

Fig. 3 Outdoor microclimate simulations for boarding houses (simulated by authors)

Whereas, after intervening the facades with greenery, the external air temperature at pedestrian height within 10 metres of the panel houses show that: from the lower temperature zone next to the building, each temperature zone is 4 to 28 square metres larger, with an overall temperature drop of approximately 0.1℃ and up to 0.2℃ at the tunnel between the East panel house and the two adjacent buildings on the East side. The overall trend of temperature change at this height did not change. At the height of 35 metres the data shows that the 34.30℃ to 34.31℃ zone between the two panel houses is eliminated, while the 34.16℃and lower zone increases by 16 square metres. The surface temperature of the façade directly affects the air temperature in its vicinity. Thus this simulation data indirectly shows that the intervening panel house facade with greenery has a positive effect on reducing the surface temperature of the wall, which in turn can have a positive effect on mitigating the indoor temperature, which is also in line with the established findings listed in the table. In addition to the temperatures within 10 metres of the panel house, the simulation data also shows that the vertical greenery intervention has a better cooling effect in association with the existing trees nearby, as can be seen in the Fig. 3 at coordinates (x=30,y=100), even at a height of 35 metres, where an additional 34.16℃ cooler zone can be seen. It can therefore be seen that the preliminary simulation results indicate that the vertical greenery intervention on panel house has both a positive moderating effect on indoor and outdoor thermal comfort in the condition of Summer in Pécs. Furthermore, the intervening greenery interactions between the panel houses are more effective under the conditions of more scaled green interventions. Based on the findings of the previous literature, it can be assumed that the vertical greenery interventions on panel houses have a positive impact on reducing energy consumption and mitigating the heat island effect.

VI. CONCLUSION

VGF plays a role in architectural design to increase the amount of urban greenery and has the ability of reducing the outdoor air temperature to different extends, and this study emphasises green intervention and urban renewal targeting stock buildings. This paper investigates the effect of vertical greening systems on the thermal comfort of the outdoor environment of one representative residential building type in Summer situation in the Central European town of Pécs. From comparative measurements by applying VGF, it is possible to reduce the air temperature in the external environment at both pedestrian level and top level. From thermal comfort point of view, this effect is expected to lead to energy savings in air conditioning and to a reduction of the urban heat island effect. It can also be noted that, based on the fundamental theory of VGF, the vertical greenery intervention on the panel houses promotes noise reduction and adjusts the pedestrians’ experience in buildings’ adjacent public space to positively influence the living environment. After the study of the outdoor environment in Summer, a quantitative study of indoor and outdoor thermal comfort in Summer and Winter, the applicable plant species, and the adaptability of the installation system are further planned.

Through a complete series of vertical greenery interventions in the Pécs, it is expected that the widespread distribution of greenery in the Pécs will lead to a universal strategy of sustainable urban regeneration and in meantime to a resilient life style.

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