Mapping Plant Microclimates on Building Envelope Using Environmental Analysis Tools

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Abstract. Can we build our cities not only for humans but also for all living systems? How can we consider other species occupants of the built environment? Planning cities as an element of the natural domain can reshape our relationship with nature and help redefine sustainability in architecture. Although current design strategies of reducing energy use does not rectify past/continuing im-balances in the natural environment. Landscape architect John Tillman Lyle expanded the regenerative design concept based on a range of ecological concepts. The environment's complexity, and the urge to use resources smartly, encouraged him to think about architecture and the environment as a whole system. John Lyle's regenerative design strategies scaffold a conceptual framework of treating the building as part of the landscape. Environmental tools such as Ladybug can map out the different conditions surrounding the building's envelope. This information can assist in selecting and populating a building façade with suitable plant species. The framework presents the building as a feature in the landscape, creating microclimatic conditions for various plant habitats. This conceptual workflow has the potential to become a tool to include regenerative principles in the urban context.

Keywords: Regenerative architecture · Bio digital architecture · Sustainable architecture · Urban ecology · Environmental analysis

1 Introduction

Can we use architecture to create new ecological relationships to improve nature[1] in urban areas? What if buildings supported native plants and animals? Human development modifies the surface and landscape soil, destroying small ecosystems or flooding entire valleys. Such interventions accelerate the loss of vegetation, impacting the ecology of the non-human inhabitants of these areas. Planning cities as an element of the natural domain can reshape our relationship with nature and help redefine sustainability in architecture.

[1] With linguistic evolution in popular language, scientists and philosophers have remained cautious with this word. In this paper 'nature' is a term referring to scientific concepts such as "biodiversity", "evolution", "ecosystem", "landscape", "wildness", "population", "community"; the whole of material reality, considered as independent of human activity and history [19].

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Instead of separating developed zones from nature, it is worth considering our cities as another layer of the landscape, an “open system” of living things that constantly interact with the physical environment [1].

The climate effects of cities result from the urban form of the landscape (extent, materials, building dimensions and density) and urban function (energy, water and material use through the urban metabolism). Increasing vegetative cover and incorporating natural landscape features into cities are the best means of managing climate effects in developed areas [1]. This situation allows us to reconsider current contemporary planning and design methods for sustainable urban growth and recognise the need to design and plan with nature. The current scenario requires a behaviour change by acknowledging our responsibility and vulnerability, to changes in the natural environment [2].

John T Lyle (1934–1998), a professor of landscape architecture at Cal Poly Pomona from 1968 to 1998, developed an approach to design that he called regenerative. His strategy was based on improving resource efficiency and considering solutions that would have a circular life cycle. His design system inspired a conceptual framework to design the built environment for humans and also to consider nature as occupants of the urban space.

Planning cities as an element of the natural domain is a way of rethinking our relationship with nature and redefining sustainability in architecture. Instead of separating developed zones from nature, it is worth considering our cities as another layer of nature. Analogous to a tree, the microclimate on the top of a building will differ from the bottom, requiring different architectural solutions. Environmental tools such as Ladybug can map out these different microclimates throughout a building’s exterior. The environmental analysis set to evaluate the whole building’s climatic conditions can result in the information necessary to populate the building envelope with adequate plant species. Architectural elements can be inserted into the design to protect and benefit the building’s green walls and roof. This conceptual work envisions activating ecological relationships within the built environment, aiming to improve the urban ecosystems instead of focusing on humans and building interiors.

2 Regenerative Design

During the 1970s, the awareness of the impact of human civilisation on the environment changed the way people think about the resources. Altering the way, we think would help us recognise that the natural systems would have to be part of the design process [2]. Regenerative design theories emerged from early sustainable development, which attempted to integrate environmental responsibility, social equity, and economic viability [3]. Many regenerative design outlines appeared since the 1970ties, such as permaculture, developed by David Holmgren, Robert Rodale’s regenerative organic agriculture or ecological design, where Sim Van Der Ryn describes restoration and regenerative strategies.

Sustainable design, to John Lyle, endeavours to minimise harm and have a neutral impact on the environment; however, he pointed out that it did not address the harm that human growth had caused to the environment [2]. He explained that landscape throughout time had been conceived in a superficial manner, where the architects were only interested in what was seen on the surface, only concerned visually. Lyle called this approach “shallow forms”. All parts within the ecosystem should be considered for a system to be sustainable [6].

John T Lyle expanded the concept by incorporating ecological theories into design [4]. The findings of the environment’s complexity, and the urge to use resources more smartly, encouraged him to think about architecture and the environment as a whole system. Lyle’s theory focuses on designing landscapes to support ongoing supplies of energy and materials for habitat, daily living, and economic activity, replacing the linear material flow system with a cyclical use of resources [5].

2.1 Regenerative Design Strategies

Considering that natural and social processes make the design more com-plicated, requiring a solid framework. Lyle developed a set of hierarchies in his book Regenerative design for sustainable development to address such complexity. Everything that exists in the natural and built environment has an order.

Lyle’s regenerative design, this organisation is called “structural order”, which describes the composition between living and non-living. In considering the structure of an ecosystem, all its elements are recognised: rocks, soil, plants, and animal species [7]. Each species inhabits a particular niche in natural eco-systems and maintains ongoing interactions with other species.

The more complex the regeneration goal, the greater are the challenges for de-sign, requiring a different pattern of thought. John Lyle listed some of his de-sign strategies in his book as a “tentative effort to summarise the experience” he had [7]. Nature is highly evolved in water conversion, distribution, filtration assimilation, and storage processes if undisturbed. As a result, using natural processes as a regeneration strategy requires an investigation of on-site resources and processes.

There are current projects that applies strategies introduced by Lyle such as Illura Apartments (Fig. 1) model how architects can contribute to ecology. The Australian building has a green façade that was seeded with grassland species that have been extinct in the area since colonisation, resulting in a resilient green façade that restored the native ecosystem. Projects like this illustrate that incorporating the plants at the early design stages can result in restorative design.

Lyle’s second mode of order is the “functional order”, related to the flow of energy and materials that distribute the necessities of life to all the species belonging to an ecosystem. These flows determine the dynamic of ecologies and often explain the change it undergoes. Every landscape receives energy from the sun, which is absorbed or reflected by the planet’s surface, warming the atmosphere and water, and powering the water cycle. The energy is fixed into living matter by photosynthesis, making its way through the food web and supplying other creatures with energy [7].

Industrial systems use resources independent of the overall flow. Fossil fuel, for instance, makes minimal use of solar energy to maintain heat balance within a building, virtually independent of the larger regional and global heat balance [7]. Lyle proposes that understanding the flows of a locality can promote the development of the site location. In controlling the flow of stormwater, the form of the landscape can hold the water as in a bowl while it penetrates the underground storage, for example.

Fig. 1. Illura apartment buildings **by Elenberg Fraser** in Melbourne, Australia. on the right, the detail of the green facade. Photo: **Peter Clarke**

The last order proposed by John Lyle is the "Locational Patterns". John Lyle suggests that each location has its requirements, and that the development of each area should follow the local parameters. When life appeared on Earth, its evolution was guided by several climate and geological compositions. The species that thrive in a desert are very different from those that thrive in a rainforest. Industrialisation changed the urbanscape. Buildings and cities were an integral part of their location, whereas now, a high-rise office building in South America is not too different from a high rise in North America. Both [7].

Green infrastructure intends to control urban sprawl and protect nature [8] Initiatives to convert urban environments into gardens to increase the ecological base, such as "Green Scaffolding (GS) (Fig. 2), a concept for a modular system that wraps around the façade of an existing building, provide multiple ecosystem services and environmental amenities [4]. Such structures can be established in different sizes, types, and scales. Depending on the design, the structures can provide thermal comfort, help with urban acoustics, or serve as shelter for local species from invasive species [5]. Although these initiatives are a positive manifestation of addressing ecology and climate issues in urban areas, they do not consider nature as a whole. They are just adding patches of green in the city, accentuating the clear separation between built-up areas and nature. No restoration or significant improvement to the natural environment is achieved with Green Scaffolding.

3 Environmental Analysis, Microclimate, and Vegetation

John Lyle's regenerative design inspired a framework to include the vegetation as an 'occupant' of the built environment. Following Lyle's design strategy of letting "Nature does the work" improve the natural flow of energy [7], the proposed workflow will perform an environmental analysis on a building geometry to map out the existing outdoor conditions of a building. Plants thrive where the conditions are correct. It requires the right amount of sunlight, filtered sun or shade. They also depend on the correct

Fig. 2. Eco Boulevard was designed and built in Madrid, Spain, by Ecosistema Urbano. Photo by Emilio P. Doiztua

humidity levels [9]. The evaluation will determine the plant species suitable for each surface area and assist in designing the building to protect the green wall.

3.1 Environmental Analysis

The majority of microclimate evaluation software is not integrated into mainstream architectural software. However, open-source platforms such as Grasshopper and Dynamo, along with their plugins, have made the integration of environmental data more accessible. A better understanding of climate data and human comfort indices impacts designing resilient and energy-efficient buildings [10]. Plugins such as Grasshopper's (Rhino 3D) environmental analysis plugins are used within architectural design environments to offer a socio-ecological assessment during the design decision-making [11]. This tool allows the designer to know the environmental conditions that characterise a given urban environment to mitigate the adverse effects and exploit the positive ones to ensure optimal comfort conditions [12].

Ladybug tools are one of the standard environmental tool analyses, and it has been selected as they can cope with complex and straightforward geometry [13]. Ladybug imports standard EnergyPlus Weather files (.EPW) into Grasshopper and Dynamo. It provides a variety of 2D and 3D interactive climate graphics that help the decision-making process during the early stages of design. The plugin supports evaluating initial design options through solar radiation studies, view analyses, and sunlight-hours modelling. Honeybee provides detailed daylighting and thermodynamic modelling that tends to be most relevant during the mid and later design stages. Specifically, it creates, runs, and visualises the results of daylight simulations using Radiance, energy models using EnergyPlus/Open Studio, and heat flow through construction details using Berkeley Lab Therm/Window. It accomplishes this by linking these simulation engines to CAD and visual scripting interfaces such as Grasshopper/Rhino and Dynamo/Revit plugins. Butterfly is a Grasshopper/Dynamo plugin and object-oriented python library that creates and runs computational fluid dynamics (CFD) simulations using OpenFOAM.

At present, OpenFOAM is the most rigorously validated open-source CFD engine. It can run several advanced simulations and turbulence models (from simple RAS to intensive LES). Butterfly is built to quickly export geometry to OpenFOAM and run several standard airflow simulations applicable to building design. This includes outdoor simulations for urban wind patterns and indoor buoyancy simulations for thermal comfort and ventilation effectiveness [10].

3.2 Microclimate

Climate is a critically significant factor for an organism to thrive, and it involves many components such as temperature, rainfall, relative humidity, and winds. The microclimate on the top of a building will differ from the microclimate on the bottom. To include the natural order in building design is important to understand that the building itself should be treated as a feature in the landscape that creates microclimatic conditions for various plant habitats.[2] Environmental tools such as Ladybug can be a way of mapping these different microclimates throughout the exterior of a building, providing the information required to determine the multiple plant habitats.

The microclimate describes the conditions of sun, shadow, temperature, and humidity in each precise location within a macroclimate. Plants and animals experience the microclimate of the exact location where they live, for example, in full sun and wind at the top of a tree or in the shade, stillness, and humidity at its base. It is different from the meteorologist's climate (macroclimate). The physical processes and factors creating a microclimate: solar radiation, air humidity and temperature, and wind velocity vary widely depending on the physical conditions of the surroundings and affect the local distribution of plants and animals and their communities and the local survival of populations [14].

Changes in temperature and humidity are most significant near the ground, absorbing a high proportion of the earth's share of the sun's energy. When the sun shines on the ground, the surface temperature rises, and a temperature gradient is set up. Since the relative humidity of the air is related to the saturation vapour pressure, which is directly related to the temperature, the gradients of temperature and near the surface typically mean that gradients of relative humidity also exist. Dennis Unwin, from the Department of Zoology at Cambridge University, explains that to paint a picture of the climate requires knowing how the temperature the humidity parameters vary. Since the driving force behind the whole system is the sun, it is also essential to measure solar radiation and its variation with time [15].

The climate parameters measured in this study are sun hours, wind, humidity, and radiation. The average temperature of the habitat is not as central as its extremes, which

[2] The habitat is the condition in which an organism completes its life cycle. Habitats have two types of components: the abiotic, which are the nonliving components, such as climate, soil, latitude, altitude, and disturbances such as fires, flood, and avalanches; and biotic are the factors that are living such as the plant itself, other plant species, animals, fungi, protists, and prokaryotes [3].

are the lowest winter and highest summer temperatures [16]. Latitude contributes to many factors to the abiotic environment, such as hours of sun exposure throughout the day. It also influences how the light strikes the plant. Light strikes the Earth obliquely when the sun is low, and less energy is received per square meter. High altitude regions have higher winds and more intense ultraviolet light [3].

The proposed workflow involves presenting to the grasshopper plugin, Ladybug, a context geometry, and a subject building. The subject location presented in this paper is a random site in Melbourne, Australia (Fig. 3). There were no urban planning considerations as the purpose is exclusively to illustrate the framework.

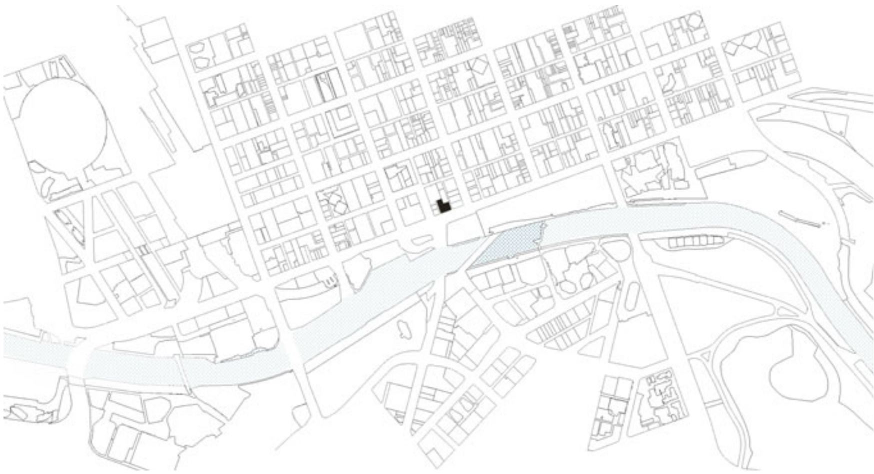

Fig. 3. A hypothetical site in Melbourne, Australia marked in black (image by author)

The environmental tool is set to analyse the whole building's humidity, radiation, and sun exposure. The analysis period relevant to determining a microclimate is the hot and cold, extreme temperatures. Consequently, the evaluation period will be 24 h during midsummer (Fig. 4) and mid-winter (Fig. 5). Each investigation will build a set of data: the sun hours, the radiation throughout 24 h and the relative humidity (Fig. 6) during the analysed period.

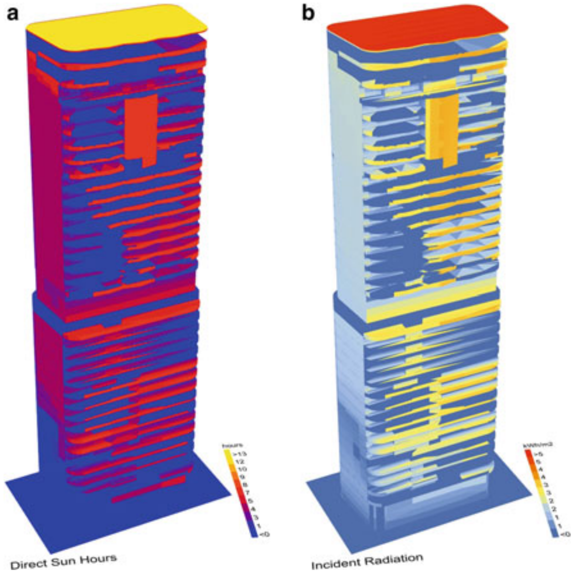

Fig. 4. Analysis of direct sun hours (**a**) and radiation (**b**) in mid-summer. (3D image by author)

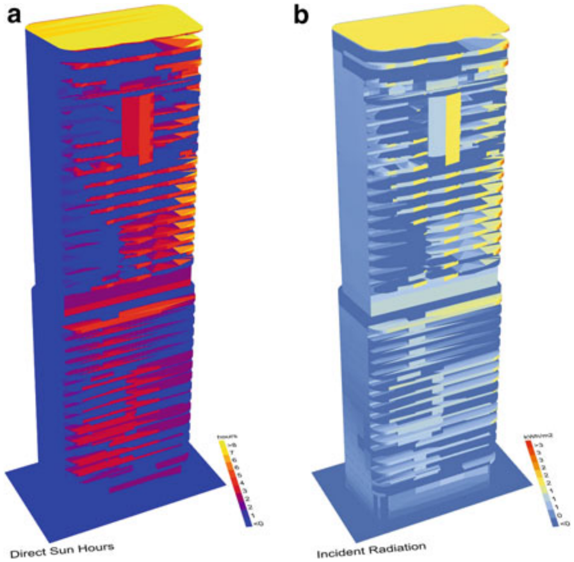

Fig. 5. Analysis of direct sun hours (**a**) and radiation (**b**) in mid-winter. (3D image by author)

The surface temperature calculation requires a material. For the example pre-scented in this paper, a generic material was selected to simplify the calculations. A python script

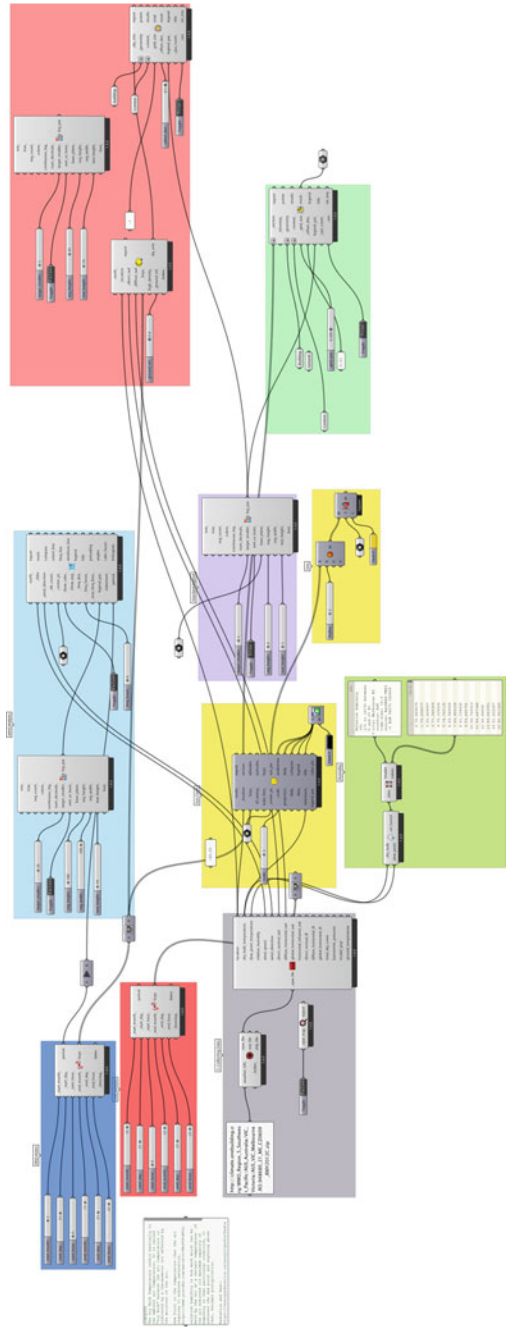

Fig. 6. Grasshopper/Rhino 3d definition showing environmental analysis. Relative humidity data is highlighted in green (image by author)

for Grasshopper compared the analysis result with the parameters that define microclimates (Table 1). The outcome is a coloured geometry, where each colour represents specific climate conditions (Fig. 7).

Fig. 7. Grasshopper/Rhino 3d definition showing environmental analysis. Relative humidity Each colour represents a different microclimate. The colours result from the cross-reference between the environmental analysis and the microclimate parameters. (3D image by author)

Table 1 The table shows the parameters that define the different microclimates. The information was extracted from the Australian Bureau of Meteorology [17]

Climate	Station number	Monthly mean daily global solar exposure (kwh/m^2)		Min temperature celsius of year (2012–2022)	Max temperature celsius of year (2012–2022)
Climate A	83085	1.39	7.83	−10.4 to −7.6	21.5–28.2
Climate B	96033	3.67	4.08	−8.1 to −14.2	26.6–32.3
Climate C	75032	4.89	5.31	−4.6 to −2.2	39.5–47.2
Climate D	15135	6.00	6.44	6.2–8.5	41.9–45.6
Climate E	14932	6.11	6.50	4–8.5	40.6–43.1
Climate F	28004	5.78	6.17	5–10.3	35.7–41.7
Climate G	14142	5.47	6.03	12–15.9	35.8–36.8

This information will help select and populate the building façade with suitable plant species, as the analyses provide details of the building envelope's particular conditions (Fig. 8). The wind analysis will assist in the development of the façade elements. These components will direct the airflow where plants benefit from wind and protect the vegetation that requires protection from the weather (Figs. 9, 10 and 11).

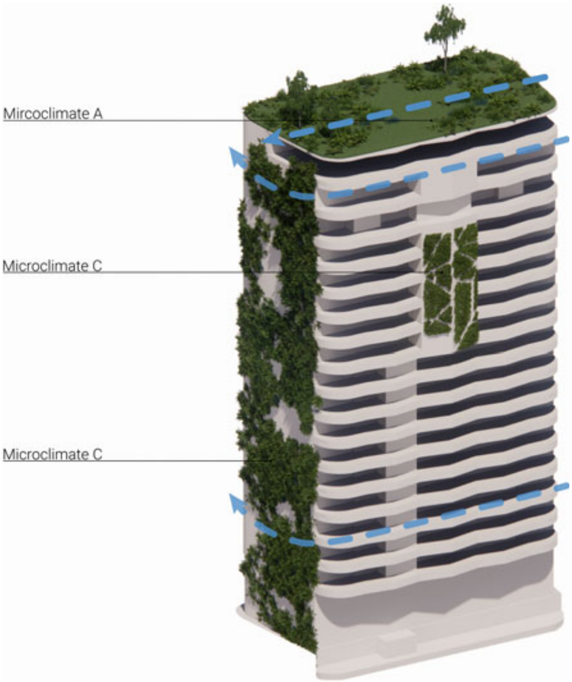

Fig. 8. Each microclimate will define a different plant species that will populate the building envelope. The dotted lines above show the wind direction. (Model by author, rendered by Taylor Ristevski)

4 Conclusion

The climate effects of cities result from the urban form of the landscape and urban function. Increasing vegetative cover and incorporating natural landscape features into the urban design are the best means of managing urban climate effects at all scales [1].

This situation serves as an opportunity for us to reassess current planning and design methods for sustainable urban development and recognise the importance of ecological systems as an integral part of our planet. Consequently, the current scenario requires a behaviour change by acknowledging our responsibility, vulnerability, and reconnecting with nature [18]. Although sustainability reduces environmental harm, it does not rectify past/continuing imbalances in the natural environment. There is a clear separation

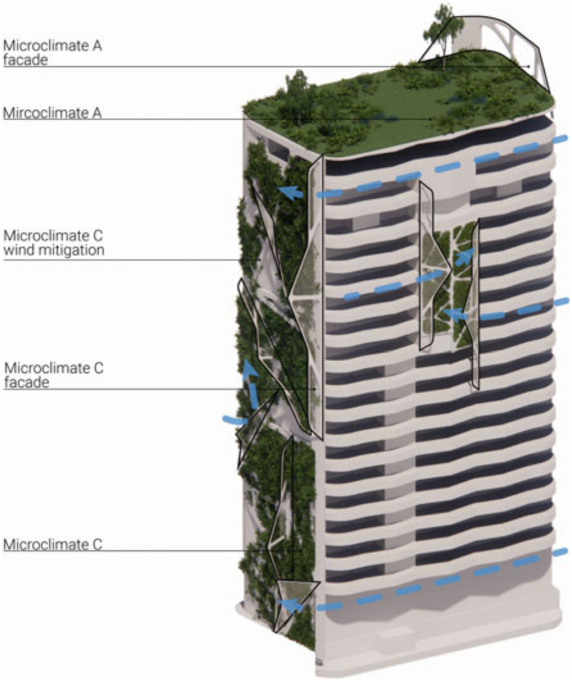

Fig. 9. Façade design to protect vegetation. (Model by author, rendered by Taylor Ristevski)

between developed areas, and nature and green infrastructure are initiatives exclusively human-centred.

Environmental tools such as Ladybug can be a way of mapping out these different microclimates throughout a building's exterior. The environmental analysis is set to evaluate the whole building's climatic conditions, resulting in a coloured geometry, where each colour represents a distinctive microclimate. This information can help select and populate the building façade with suitable plant species.

This assessment can be used to select the suitable plant species for the building façade, and it can also assist in decision-making concerning the overall configuration of the building. The wind evaluation is performed after the plant selection, guiding the design of the façade. The façade elements will perform the task of protecting or channelling the wind towards the plants. Advancing this environmental tool is valuable to facilitate the incorporation of regenerative solutions in the built environment and to provide opportunities to strengthen existing ecosystems. The difference between adding a traditional green wall to a building and this framework is that the design is done for the vegetation to thrive instead of populating buildings with plants to suit the indoor conditions only.

Fig. 10. Detail of façade elements. (Model by author, rendered by Taylor Ristevski)

Fig. 11. Building in context. (Model by author, rendered by Taylor Ristevski)

One of the challenges to developing this framework is the environmental factors that need to be measured for more accurate results, such as the air temperature near the building surface, which are difficult to predict accurately. That happens because the current tools are focused mainly on indoor comfort. This method also addresses the philosophical issue of our anthropocentric behaviour as it includes nature not only as part of the design but also as a "user" of the architectural space.

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