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EXPLORING GREEN FAÇADES AS COMPLEX SYSTEMS AND THEIR RELATIONSHIPS WITH SOUNDSCAPE QUALITY THROUGH A SYSTEMS THINKING APPROACH

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ABSTRACT

Green façades, on which plants grow, are increasingly prominent in research and industry. They provide benefits beyond conventional façades. All façades act as a buffer between the outdoor and indoor environment, regulating heat, moisture, light, pollutants and sound. Green façades carry these forward—reducing the urban heat island effect, boosting biodiversity, providing food, improving the microclimate for sound and air quality, and increasing access to nature, which has major benefits for health. Research to date has primarily examined isolated aspects of green façades, such as their impact on outdoor noise reduction, often focusing on correlations rather than causality. This narrow approach overlooks the broader, interconnected relationships between the numerous variables influenced by green façades, including the interplay between façade-induced biodiversity and both outdoor and indoor soundscapes. This study aims to untangle these interdependencies through a participatory systems thinking approach—a method that has yet to be applied to green façades. It is based on participatory systems thinking workshops involving multidisciplinary topic experts and industry professionals. Workshop findings result in causal loop diagrams, with preliminary results presented here, highlighting relevant variables, feedback loops, and intervention points that characterize the relationships between façades, soundscape, and other domains intertwined in this complex system.

Keywords: *green façade, soundscape, systems thinking*

INTRODUCTION

Green facades are complex technological systems that are increasingly studied and implemented in cities [1]. While their installation and maintenance costs can be significant, they can offer a wide range of impacts across various domains. In the literature, several authors have explored cost-benefit analyses, which are essential for assessing the viability of these systems [2,3]. For example, Perini and Rosasco conducted a private and social cost–benefit analysis of vertical greening systems [3]. The personal economic benefits they considered were related to real estate value, energy savings for heating and air conditioning, cladding longevity, and tax incentives. Meanwhile, the social costs and benefits included improvements in air quality, carbon reduction, habitat creation, aesthetic impact, urban heat island mitigation, and tax incentives associated with installing vertical greening systems in urban areas. Other studies

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have sought to map the potential benefits and barriers to adoption, aiming to create a more accurate cost-benefit assessment and identify ways to overcome obstacles that hinder implementation [4].

In terms of impacts on the acoustic environment, studies have focused on characterizing green walls in terms of their ability to absorb and scatter sound, which may reduce noise levels in street canyons, as well as their contribution to facade sound insulation [5,6]. While many studies investigated individual or partial aspects of green façades, what we believe is missing is a holistic perspective capable of untangling the complexities of green façades and their contributions to technical, economic, social, public health, and environmental benefits. These impacts are multifaceted and interrelated, and considering them holistically requires a broad range of expertise—spanning biodiversity, food production, access to nature, health and well-being, social connections, air quality, soundscapes, and sensory experiences for individuals interacting with buildings where these systems are installed. Such knowledge can be useful for policymakers, building managers, designers, as well as final users.

This paper is part of a research project that examines green façades as complex systems through a systems thinking approach based on participatory workshops. Systems thinking explores interconnections between elements related to a given issue [7], focusing on understanding the dynamics that influence each other and shape the overall behaviour of the system [8]. This approach has recently been applied to studying the relationship between soundscape and public health [9], resulting in qualitative maps known as causal loop diagrams (CLDs), which have proven effective in graphically representing complexity.

This study presents the general methodology to be followed in analysing green façades as complex systems, briefly introducing the systems thinking framework and highlighting the benefits of such an approach when examining the relationship between soundscape quality, green façades, and other interrelated variables.

METHODOLOGY

The overarching research project, "*Facades in the Loop: Embodying the Role of Green Facades in Enhancing Sensory Experiences, Biodiversity, Food Production, Environmental Quality, Health, and Wellbeing in Cities through Participatory Systems Thinking*" adopts a participatory systems thinking approach. Through dedicated workshops, a diverse group of stakeholders with varying backgrounds and expertise collaborate to identify the variables influenced by green façades, map their interconnections, and determine the polarity (positive or negative) of each relationship. This approach is particularly valuable as it moves beyond linear cause-effect thinking, instead emphasizing feedback mechanisms—how initial changes within a system can trigger further, often nonlinear, transformations across different sectors. It also helps identify intervention and leveraging points within the system. Within the developed CLDs, two key types of feedback loops can be distinguished: reinforcing loops, which amplify effects within the system, and balancing loops, which counteract changes. By graphically representing these dynamics through a participatory approach, the process allows for the integration of diverse perspectives, ultimately enhancing the understanding and management of the system.

The workshops build upon preparatory work carried out in an online pre-workshop with project participants. The workshop lasted one hour, was moderated by a CLD expert, and involved 8 experts in the fields of acoustics and soundscape, biodiversity, facade technologies, architecture, agriculture, and indoor and outdoor environmental quality. During this preliminary phase, an initial list of variables and key interconnections was identified, serving as a foundation for future in-person workshops, where the variable set will be expanded and the model further refined.

The following section presents an example of a causal loop diagram focusing on acoustic variables related to green façades, highlighting their links to other non-acoustic domains.

RESULTS

The preliminary group modelling exercise conducted online among project team members identified a set of variables related to acoustics and green façades, as illustrated in the proposed CLD in Fig. 1. Vegetation on façades is known to be positively linked with façade sound absorption and diffusion, thereby reducing external reverberation and noise levels, particularly in urban street canyons [2,10]. This leads to a decrease in noise pollution, which, in turn, is negatively linked to window opening [11]. Specifically, a reduction in noise pollution is expected to increase window opening for ventilation. Indeed, building occupants may be reluctant to open windows to ventilate the indoor space, due to

intrusive noise from the outdoors, hence relying more on HVAC-based cooling/ventilation (and increasing operational costs). A wider adoption of passive ventilation strategies may thus enhance building energy efficiency [12], freeing up resources that can be potentially reinvested in the creation and maintenance of green envelopes. This set of links describes an external reinforcing loop, highlighted in black in Fig. 1.

Additionally, green façades can attract animal and invertebrate species [13], increasing biodiversity [14]. This, in turn, enhances soundscape quality [15], which may further encourage greater use of window opening for ventilation [11], thus connecting back to the previously identified loop (Fig. 1, in blue). Another reinforcing feedback loop emerges among biodiversity, soundscape quality, and noise pollution: an increase in biodiversity improves soundscape quality, which in turn reduces noise pollution [15], thereby further supporting communication, and reproduction among species [16] (Fig. 1, in green).

Moreover, façade vegetation can enhance the view to the outside, which contributes to improved soundscape quality due to well-documented audiovisual interactions [17].

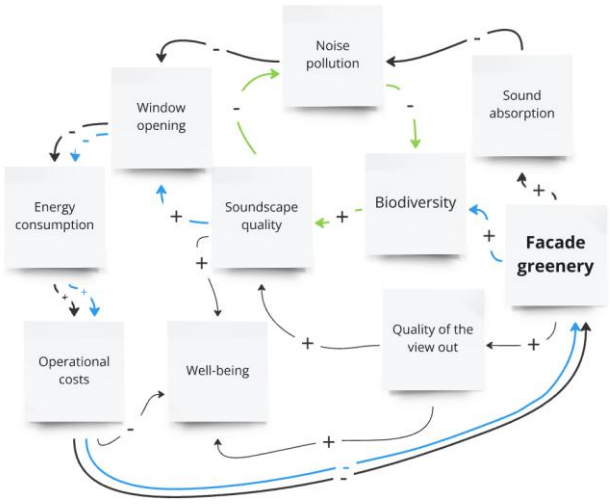

Figure 1. Causal loop diagram resulting from a workshop with team members. Three loops are highlighted in green, blue and black. The thickness of the lines represents the highlighted mechanisms for illustrative purposes and does not indicate the strength of the connections.

Finally, soundscape quality [18,19], external views [20], and reduced building operational costs are all positively linked to human well-being. Notably, reduced operational costs will most likely result in reduced financial pressure on building occupants; we expect this to have a positive impact on well-being, especially for tenants who may be struggling with the cost of living crisis.

DISCUSSION

This contribution has presented the preliminary results of an ongoing study analysing green façades as complex systems, with a particular focus on their acoustic impact on both humans and ecosystems. Compared to previous cost-benefit analyses, this qualitative modelling approach provides a more comprehensive disentanglement of the numerous interactions at play in the case of green façades and the sound environment. Historically, the acoustic literature on green façade impacts has primarily focused on their effects on outdoor reverberation—through absorption and scattering phenomena—and noise reduction at the façade or street level [10,21]. To the best of our knowledge, this is the first time a link has been theorized between green façades and soundscape improvement through the attraction of animal species, whose presence might be audible both outdoors and indoors when windows are open for ventilation.

Window opening emerges as a key element in establishing a connection between indoor and outdoor environments, enabling exposure to a potentially positive external soundscape that can benefit well-being while also promoting passive ventilation and cooling strategies [22] that, in turn, reduce building energy consumption.

Indeed, as highlighted in recent research, while outdoor noise pollution is a major factor driving window closure—especially for noise-sensitive individuals—acoustic connection with the external environment can encourage window opening in comfortable contexts [11].

Ultimately, human well-being is central to this study, both directly, through the sensory experience of sound and visual landscapes, and indirectly, as the presence of visible greenery can modulate and enhance acoustic perception. The CLD proposed here represents an initial draft that will be expanded and validated through workshops with academic and industry experts, incorporating further interrelations and feedback mechanisms related to sensory experiences, biodiversity, food production, environmental quality, social

connection, and public health, among others. While reinforcing loops have emerged in the CLD outlined here, it will also be interesting to identify potential balancing loops, which represent system constraints.

A key strength of the systems thinking approach is its ability to explicitly, transparently, and holistically capture the complexity of the variables associated with green façades—whose effects are documented in fragmented, discipline-specific literature. This methodology not only strengthens cost-benefit analyses but also provides a foundation for future interdisciplinary research, fostering a more integrated understanding of green façades´ multifaceted impacts.

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