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SHORT COMMUNICATION

A Residential Building Extension Prototype to face Post-Pandemic Needs: Foreseen Challenges and Impacts

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Abstract

The COVID-19 pandemic highlighted the importance of outdoor spaces for maintaining physical and mental well-being. However, many urban residents lack private outdoor areas, which led to harmful health consequences during lockdowns. The research project aims to address and solve this issue by developing a physical/digital prototype called "X-TEND" that extends living space outdoors by attaching it to existing multi-story residential building facades. This prototype intends to promote healthier lifestyles, improving the well-being of individuals and positively impacts the urban surroundings aesthetics. X-TEND prototype uses a light, modular, and prefabricated approach for cost-effectiveness and environmental sustainability. It incorporates generative processes for structural and bioclimatic optimisation complemented by green building strategies to reduce environmental impact while maximising thermal and energy performance. Ultimately, X-TEND prototype contributes to a more sustainable built environment, fostering healthier and more liveable cities for current and future generations.

Keywords: building extension, balconies, outdoor space, post-pandemic, X-TEND

1. *Introduction*

The importance of private outdoor spaces, such as terraces or balconies, increased during the COVID-19 pandemic due to the successive mandatory confinements decreed by government institutions [1]. As people spend more time at home, the value of having a safe and private outdoor area has increased, as it enables outdoor leisure activities and connection with nature and provides a sense of physical and mental escape [2, 3]. In addition, the lack of access to public outdoor spaces has resulted in a shift of certain outdoor activities to more secluded and private areas. As a result, the idea of a balcony or terrace has emerged as both a solution, allowing people to enjoy the outdoors, sunlight, and fresh air, and a challenge for designers who must now adapt their designs to meet the evolving needs of users [2]. Therefore, this issue demands new dimensional requirements and design adjustments in new or existing balconies or terraces, mainly in highly populated urban areas [4].

However, from the research team's standpoint, the situation of multi-story residential buildings, where architecture did not address this kind of spaces (e.g., balconies, terraces, patios) is concerning and problematic, particularly in social housing buildings (Figure 1). As stated by D'Alessandro *et al.* [5] a survey performed in Italy by the *Istituto Nazionale di Statistica* (ISTAT) in 2018 indicate that 11.4% of the apartments, representing around 2,650,000 families, were lacking outdoor private spaces like balconies, terraces, or gardens at home. This lack of provision fails to ensure user access to private outdoor spaces and the related benefits.

Figure 1. Lack of outdoor private spaces in a multi-storey residential building in Lisbon (left) and Warsaw (right). Captured by the authors (02-05-2023 and 20-07-2023, respectively).

On top of this, several studies state that the lack of balconies or poorly designed ones, coupled with inadequate urban spaces, played a role in the decline of the population's physical and mental health during lockdown periods. Although the affected individuals came from diverse socio-cultural backgrounds and demographics [6–8], the impact was particularly severe on the most vulnerable segments of the population [5]. Other studies, such as Moreira and Farias, conducted during the first mandatory confinement in Portugal, show that 51.3% of respondents elected "outdoor space" at home as a priority when compared to other categories like "indoor habitable area", "location", or "layout". The same authors highlight the change in perception towards the domestic space and establish a new paradigm in this domain [9].

Considering this, the research team's understanding is that dwellings lacking private outdoor spaces represent social aberrations with detrimental consequences for their inhabitants, especially during times of stress and uncertainty. To address this issue, we intend to develop a research project (RP) that explores design solutions for extending living spaces outdoors in multi-story residential buildings built between 1961 and 2000. The target is buildings where private outdoor spaces do not exist, are restrictive, or display poor design quality (Figure 1). Nonetheless, we intend to push the private outdoor spaces concept far beyond a mere "home" extension, something which is widely available.

The RP's main goal is to develop a physical and digital architectural prototype called "X-TEND"—a lightweight, modular, permeable, adjustable, and easily dismountable structure that can be seamlessly integrated into the façade(s) of existing buildings. This exoskeleton structure will become the main element of an energy retrofit operation turning the existing building into Near Zero Energy Building (NZEB) or Positive Energy Building (PEB).

The X-TEND prototype aims to be implemented worldwide. However, its initial stage will involve the development of pilot case studies in Lisbon and Warsaw. Due to the diverse socio-cultural, climatic, economic, and legal backgrounds in Portugal and Poland, we anticipate challenges related to its development, implementation, and context adaptability. These challenges must be addressed to ensure its applicability in other geographies.

The present paper aims to describe the conceptual and programmatic foundation of X-TEND prototype RP, which is currently ongoing, focusing on its foreseen challenges, limitations, and societal impacts. Hence, the content presented here is purely qualitative.

We anticipate that X-TEND prototype will have a positive impact on society by providing secure and private outdoor spatial solutions where they do not currently exist, with the potential to enhance users' physical and mental well-being, improve user satisfaction, and ultimately contribute to a better overall quality of life.

We foresee the development of X-TEND prototype as a pre-emptive action against the threat of future pandemics and lockdowns while contributing to developing more resilient cities in the light of the "design to anticipate" principle by Godschalk [10]. In this context, the X-TEND conceptual foundation fits on Godschalk's "enhancing physical systems" vector, involving the preparation of buildings and human communities to endure and function even under unusual or severe circumstances [10].

2. *Literature review*

The act of designing solutions for extension of living space when it is restrictive or unqualified predates the pandemic period. We highlight the projects that transform and retrofit existing buildings developed by the Lacaton & Vassal studio (www.lacatonvassal.com): the *Quartier du Grand Parc* in Bordeaux; *Saint-Nazaire* in La Chesnaie and la *Tour Bois le Prêtre* in Paris. In these projects, the architects aimed to prevent the demolition of existing buildings by adopting an upgrading strategy extending them beyond their boundaries through the addition of a light and transparent element (a set of balconies). A trait of Lacaton & Vassal architecture is improving the dwelling spatial quality resorting to bioclimatic strategies aiming not only to improve the users' visual and thermal comfort [11] but also to address today's environmental requirements without ignoring social issues. For instance, the residents were allowed to stay during the construction works, and their projects often renovate the urban image of the neighbourhoods [12]. This works and their approach constitutes a source of inspiration for X-TEND projects. However, these projects lack the integration of renewable energy source (RES) technologies and, consequently, lack an environmental and energy assessment that would align these with the qualitative standards of NZEB and PEB.

Another related approach is the ProGETonE research project [13, 14], which aims to integrate a set of technologies into an exoskeleton that embrace a pre-existing building, with the primary goal of enhancing its seismic resistance. This project has successfully been implemented in pilot projects, demonstrating its potential[1]. Despite its high quality, ProGETonE is presented as an architecturally rigid solution and lacking environmental considerations regarding the bioclimatic suitability for a specific location or even the selection of applied materials, resorting mostly to metals.

[1] More information at: https://www.progetone.eu/project/

On a smaller, one-off scale, the *Bloomframe* [15], and *VELUX Roof Balcony* [16] solutions enable the transformation of a "window" element into a "balcony" and vice versa. However, *Bloomframe* is technologically more complex, automated, and consequently, more expensive. Despite the quality of the construction and the customisation possibilities offered by these brands, they are solutions for specific and individualised applications that do not consider the environmental and energy dimensions that we foresee for X-TEND prototype.

During the pandemic in 2020 the *STAYHÖME* was launched by Spanish architect Luís Quintano [17]. It is a modular balcony solution which can be attached to the façade and adjusted to the dimensional requirements of users and their activities. It is a low-cost solution having a wide range of applicability; however, it is ephemeral as well, and does not include RES technologies, bioclimatic optimisation or even energy and environmental consideration.

Another point worth highlighting is that, except for ProGETonE, all the other solutions lack the digital dimension, as they are unable to operate and communicate between different Building Information Modelling (BIM) software. It is also not known how they contribute to increasing the building's thermal and energy performance, and whether they have been designed with a cost-benefit logic. This is an aspect we address in the development and design of X-TEND prototype.

From an architect's perspective, well-designed private outdoor spaces such as balconies/terraces can offer numerous benefits, including solar shading, ensuring privacy, preventing glare, providing acoustic insulation, enhancing indoor thermal comfort and ventilation, improving air quality, and decreasing energy consumption for both heating and cooling purposes [18]. Given that these spaces ease the transition between indoor and outdoor, they should be designed not only to enhance a building's environmental performance but also to serve as multifunctional areas throughout the year [19]. Therefore, we must balance form, function, and composition, including their harmonious integration into the building façade [20]. The potential of these spaces to accommodate different functions defines them and makes them reprogrammable [21] not only for isolation but also for working, studying, playing, and exercising, highlighting its spatial and functional flexibility as witnessed during the lockdowns [22]. X-TEND prototype is envisioned to address all this concerns.

3. Methodology

The RP's methodology is qualitative due to its ongoing nature, and it aims to address the challenges, limitations, and societal impacts of the X-TEND prototype. The project's intentions and goals are to extend living space outdoors, design user-friendly eco-spaces, update environmental conditions, and incorporate energy production to achieve NZEB/PEB standards.

The X-TEND prototype design is based on Lean-Agile Management (LAM), which allows the project core aspects to be implemented without strict waterfall model milestones [23]. Thanks to LAM, the RP is divided into six main phases, which will be adjusted while each subsequent phase is completed. Figure 2 presents the designed workflow and phases for the X-TEND prototype project. To promote the healthier lifestyle it is needed to design a cost-effective and environmentally sustainable structure. The RP incoporates the psychological and technological aspects of designing the final stage of the X-TEND. The main aspect of the methods used in the RP was to incorporate generative processes for structural and bioclimatic optimisation.

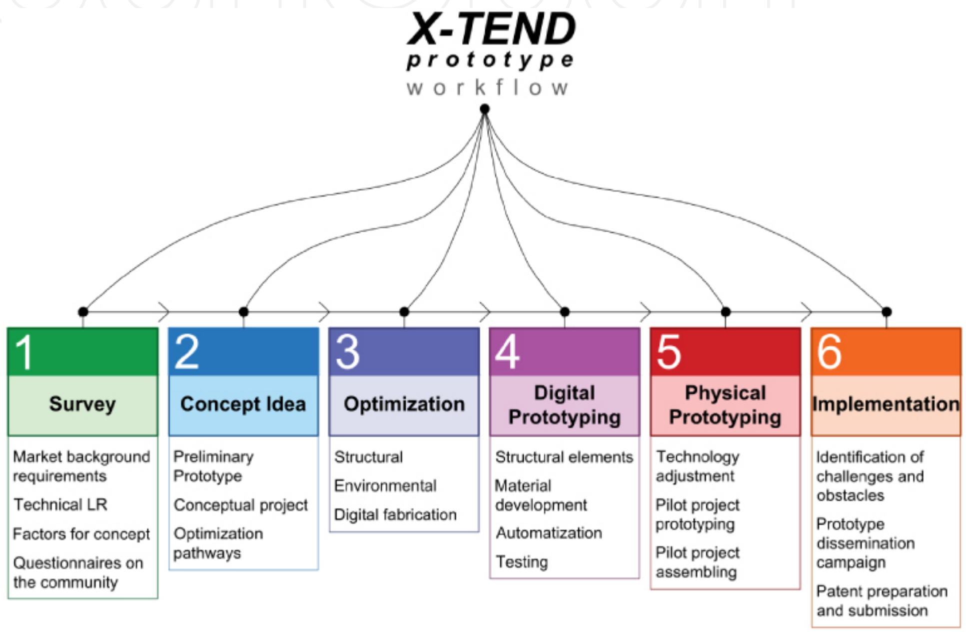

Figure 2. X-TEND prototype research project workflow.

Since the X-TEND prototype RP revolves around community engagement it started with a comprehensive survey phase (questionnaires and observations) to determine societal priorities and needs in Lisbon and Warsaw regarding the current perception and significance of outdoor private spaces [24]. The questionnaires were conducted using Qualtrics software (to ease responsiveness) and subsequently analysed with SPSS software (a widely used program for statistical analysis in Social Sciences). Hence, the LAM method is used in this RP, and SPSS, one of the most comprehensive software was used, since it can handle large amounts of data and perform various analyses. The survey phase involved questionnaires and observations to gather data from the chosen community to analyse their main habits and needs. The representational community chosen for the survey enabled statistical analyses of how the balconies are used: the frequency, function, and how people design those spaces.

The second and third phases focus on refining the conceptual Idea and cross multidisciplinary optimisations based on structural, architectural, and environmental algorithms. These stages involve conducting optimisation studies in a parametric digital environment, applying the "Design–Analyse–Evaluate–Adapt" approach outlined by de Luca [25]. This is followed by evaluating the X-TEND's energy generation potential through renewable energy systems and assessing its environmental and financial feasibility using Life Cycle Assessment (LCA) and Life Cycle Cost (LCC) analyses [26], respectively. Subsequently, a stabilised digital version of the prototype will be developed based on the insights gained from these evaluations and modifications. The X-TEND optimization tool will be developed using digital building models chosen to represent multi-story residential buildings in Lisbon and Warsaw constructed between 1961 and 2000. To implement X-TEND, designers need to provide a digital building model specifying architectural features such as the size and positioning of openings, building height, depth, shape, location, and solar orientation.

The fourth phase focuses on creating the physical and digital prototypes and assembling all the necessary construction technical documentation. This phase includes 3D printing of main nodes, fittings, and system components at scales of 1/1 and 1/2 to test and evaluate the design thoroughly. The digital prototype will be designed to be open-source and accessible to designers worldwide within a BIM ecosystem, utilising a 100% parametric tool. The aim is to achieve "ease of use" and enable automated generation of technical drawings, bills of quantities, and context-specific costs, leading to substantial time and cost savings.

The last two phases involve securing intellectual property protection for the X-TEND prototype through patenting its digital and physical format. This includes identifying potential challenges and obstacles, and seeking financial assistance for the patent application, submission, and ongoing maintenance processes. Finally, the last phase focuses on ongoing community engagement, presenting, discussing, and gathering feedback from residents to assess their receptivity to implementing the X-TEND prototype in their neighbourhoods.

The research design of the X-TEND prototype is comprehensive and multidisciplinary, involving community engagement, digital and physical prototyping, and environmental optimisation. The data collection methods are based on surveys analysed with SPSS, and the project follows a LAM approach to ensure adaptability and responsiveness to the needs identified during the research process.

4. Results

4.1. Potential application and SDGs alignment

To provide a comprehensive overview of the potential impact of X-TEND prototype, it is key to consider that approximately 85% of the European Union (EU) building stock (around 220 million units) was constructed before 2001 [27]. As of 2021, 71.3% of the EU population residing in city areas live in flats, with Portugal and Poland reporting percentages of 64.8% and 78.3% respectively [28]. According to a 2020 OECD study [29], approximately 28 million dwellings (equivalent to around 6% of OECD and non-OECD EU countries) fall under the social housing category.

Additionally, in 2019, 4% of the EU-27 population lived in overcrowded dwellings with some quality issues. Therefore, developing policies to increase investment in social housing is a priority for the EU, aiming to facilitate post-pandemic recovery efforts, stimulate economic growth, and address social segregation. This wave of investment stands as a significant pillar of the Renovation Wave for Europe in 2020 [30]. This shows the dimension of the X-TEND potential application, as well as its alignment with the European Green Deal principles, the EU Energy Systems Integration strategy [31], and the Renovation Wave for Europe [27].

When it comes to the project alignment with the SDGs, the X-TEND prototype aims to meet at least six of them (Figure 3): GOAL 3 - Good Health and Well-being;

Figure 3. United Nations SDGs aligned with the X-TEND implementation [32].

GOAL 7 - Affordable and Clean Energy; GOAL 9 - Industry, Innovation, and Infrastructure; GOAL 10 - Reduced Inequality; GOAL 11 - Sustainable Cities and Communities; and GOAL 17 - Partnerships to achieve the goal.

4.2. X-TEND conceptual description

The X-TEND prototype concept is backed by a set of seven intentions and goals that establishes the foundational basis of its development and serves as a guiding framework throughout the project's progression (Figure 4).

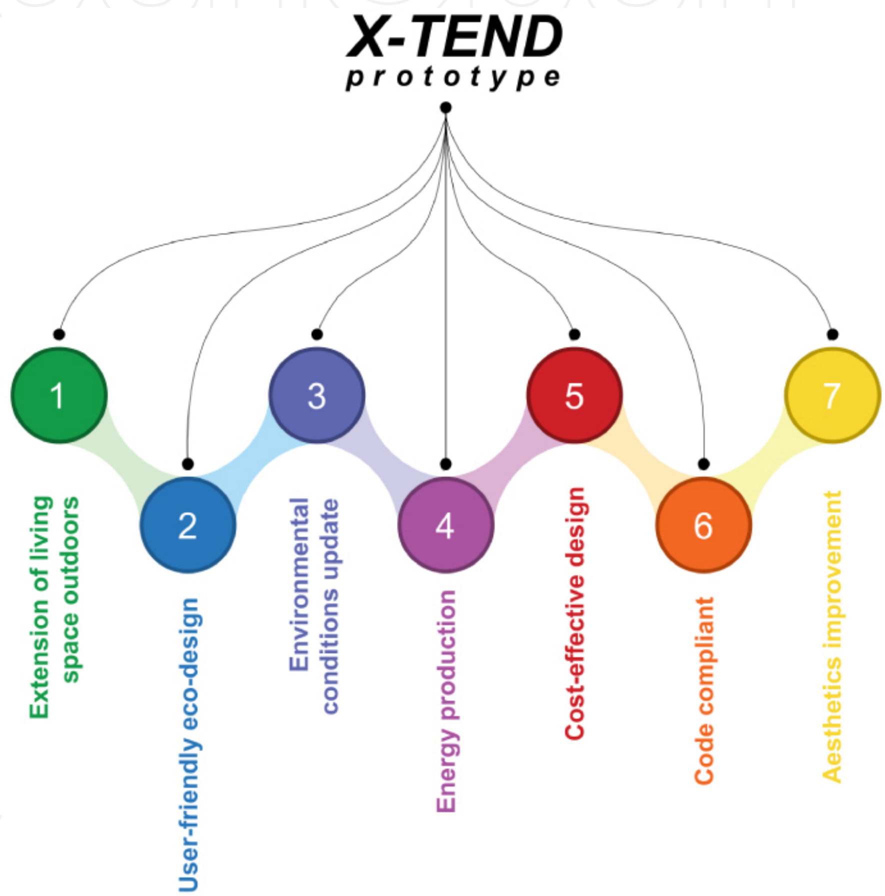

Figure 4. X-TEND prototype intentions and goals.

(1) *Extension of living space outdoors*: Provide high-quality private outdoor spaces such as balconies or terraces that extend the domestic living space and allow residents to access and enjoy them;

(2) *User-friendly eco-design*: Design and conceive private outdoor spaces that consider new influencing factors, such as local traditions, low-carbon footprint materials and construction systems, and new user dynamics and habits that have emerged in the wake of COVID-19 lockdowns;

(3) *Environmental conditions update*: Improve the existing building's acoustic, thermal, and energy performance by applying bioclimatic passive and active design strategies to optimise the X-TEND's performance in these areas;

(4) *Energy production*: Incorporate RES into the X-TEND structure to generate electricity on-site, aiming to achieve NZEB/PEB standards complying with EU decarbonisation goals for 2050;

(5) *Cost effective design*: Develop affordable "built to last" strategies that optimise production, transportation, assembly, materials, and related construction techniques, as well as maintenance, disassembly, and component reuse;

(6) *Code compliant*: Ensure compliance with current European codes and standards, meeting all safety, durability, and functionality requirements throughout the design and operation phases, and;

(7) *Aesthetics improvement*: Contribute to improving and revitalising the architectural image of the existing building, with positive impacts at an urban level (neighbourhood/city) depending on the scale of the intervention.

We envision the X-TEND prototype as an adaptable exoskeleton structure (Figure 5) that achieves the RP foundation goals simultaneously through automation processes and digital inputs. If the requirements change and differ, depending on the location of the existing building, X-TEND will also change to fit the local inputs, whether they are related to buildings codes, construction costs, or environmental and climate conditions.

Figure 5. X-TEND prototype preliminary concept using timber as a base material. Image generated with PromeAI.

4.3. X-TEND sustainability, expected transferability, and policies

Contemporary research focuses on sustainable solutions for retrofitting existing residential buildings, aiming to reduce energy consumption and environmental impact, leading to lower living costs and carbon footprint. The X-TEND prototype aligns with these principles by incorporating sustainable design principles, including modular and prefabricated logic, generative structural and technological optimisation processes, among other green building strategies. It aims to achieve the above solutions on the long run by becoming a building's second skin, enhancing its indoor conditions, and decreasing its energy consumption. Moreover, the ease in disassembly and transport of its components is another long-term benefit. The adoption of these principles can reduce the carbon footprint and improve social and economic benefits in future projects. Plus, it aims to reduce reliance on fossil fuels and transition to a sustainable energy system with local renewable solutions.

The X-TEND open-source digital prototype will serve as a universal platform for its rapid dissemination, applicability, and transferability. It has the potential to be utilised by any architect worldwide who uses BIM software.

While education and outreach programs can raise awareness about the benefits of sustainable building practices and technologies, governments can provide training and education programs for builders and designers to learn about the prevailing sustainable building practices and technologies. Additionally, they can support research and development in these fields, while combining them with modular and prefabricated constructions, bioclimatic optimisation, RES, and advancing the industry while promoting new technologies. In this way, the current RP serves as a model for shaping future codes and standards for future applications. Future projects can build on this research to develop new and innovative solutions to face societal challenges in built environment.

5. *Discussion*

5.1. Impact overview statement

Despite the number of solutions available in the market [13–17], X-TEND prototype intends to position itself as a qualitative upgrade to existing alternatives. In other words, by identifying shortcomings or less successful features in these solutions, X-TEND aims to rectify them and elevate performance at all levels.

For instance, while Lacaton & Vassal's interventions serve as a cornerstone for our RP, inspiring our vision for fostering community engagement and enhancing urban aesthetics, their interventions primarily aim at enhancing the quality of living spaces by expanding them beyond the apartment borders. In this domain, X-TEND intends to go further, by promoting an effective energy retrofit of existing buildings, not just improving indoor environmental conditions but also enabling them to generate energy from RES. Drawing inspiration from other projects and solutions alike, X-TEND seeks to harmonise the portability and functional flexibility of *STAYHÖME* [17] with the scale and qualitative scope of ProGETonE [13, 14], while maintaining cost-effectiveness compared to solutions such as *Bloomframe* [15] or *VELUX Roof Balcony* [16]. Furthermore, X-TEND will be supported by the latest insights in universal accessibility and users' dimensional and functional experience within outdoor private spaces. Its development will employ a parametric environment incorporating generative structural, thermal, and energy optimisation processes.

We foresee that implementing the X-TEND prototype will bring positive outcomes to a domestic environment in several ways. For instance, by making fresh air, sunlight, and nature accessible from private space and even enabling conversations with neighbours, we can contribute to invert the tendency to develop symptoms of anxiety and depression [7]. Similarly, improving the environmental conditions of the dwelling (acoustic and hygrothermal) increases comfort and results in better indoor air quality for users, reducing the odds of mental disorders [7] and respiratory conditions in the long run [33]. By doing so, the X-TEND prototype can play a role in minimising the physical and mental burden that has been observed during the COVID-19 pandemic according to Biju *et al.* [34], and narrow the equity gap among different population groups, particularly those living in buildings without balconies or terraces.

The "built to last" strategy and the use of eco-friendly materials align with Green Construction guidelines [35] and resonate with an increasingly environmentally conscious consumer class. Through the application of bioclimatic design strategies and RES, the X-TEND prototype enhances energy efficiency while reducing the building's energy and carbon footprint. These aspects play a crucial role in achieving the intended EU standard of NZEB and PEB level, which aims for a decarbonised building stock by 2050 [36]. Furthermore, the X-TEND prototype adheres to sustainable design practices and is intended to comply with the climate change mitigation policies defined in COP21 (Paris Accord) and endorsed in the latest COP28 (Dubai). Achieving this level of compliance could make X-TEND eligible for inclusion in government incentive programs focused on energy retrofits for buildings, and may even qualify users for tax breaks, policies often implemented in the EU.

Improving the overall building's energy performance not only leads to reduced energy costs and bills but also translates to financial savings for users, contributing to their economic well-being. Moreover, from a real estate market perspective, it is evident that balconies/terraces enhance the dwelling's quality and value [37, 38], implying that users will benefit from the property's increased worth in the future. Additionally, it is essential to note that implementing the X-TEND prototype can have a positive impact on the local economy, creating a demand for new research, installation, and maintenance professionals. The intentions regarding the prototype's financial viability are clear: to design and offer cost-effective solutions while maintaining high quality. This is a key factor in attracting potential partners and ensuring the project's economic viability.

Lastly, since the X-TEND prototype has the potential to change and improve the architectural image of buildings and neighbourhoods, its implementation can promote and foster a sense of community and belonging to a place with all the social benefits that come from it [39]. This can contribute to a more equitable distribution of benefits, as it would benefit all residents equally, regardless of their socioeconomic status or circumstances.

However, it is important to recognize the diverse socio-cultural, climatic, economic, and legal backgrounds in the pilot case study locations. These factors may pose challenges to the prototype's adaptability and implementation. Addressing these challenges is crucial and part of the optimization process to ensure that the X-TEND prototype can be effectively integrated into different contexts and provide its intended benefits to all residents.

5.2. Multidisciplinary scope and future applications

The presented RP addresses and reinforces the need to cover interdisciplinary cooperation between architectural, structural, environmental, and material engineering. Moreover, the X-TEND approach can inspire interdisciplinary collaborations in other areas beyond the Architecture, Engineering and Construction Sector (AEC). For example, transportation, urban planning, and energy researchers can collaborate to develop sustainable systems that integrate renewable energy sources, electric vehicles, and smart grid technologies on an urban scale. This collaborative approach is key to ensure that different projects cover the stakeholders' needs and expectations entirely, and positively impact society.

The recipients who can benefit from this RP include policymakers, Construction and Energy sectors, and general public. The population residing in large urban areas will benefit from living and working in comfortable and energy-efficient buildings with lower environmental footprint without the need to move away from their homes and neighbourhoods. Moreover, builders and developers can benefit from it by adopting cost-effective, modular and prefabricated construction techniques, which will reduce costs and increase energy efficiency.

While the RP's initial stages are centred on the European context, such as Portugal and Poland, it is not limited to these countries. Its fundamental concepts and premises are applicable worldwide, where social and urban vulnerabilities are often higher than in the Old Continent.

5.3. Foreseen limitations and challenges

A project of this nature inevitably faces several limitations and challenges which needs to be addressed during its development.

X-TEND prototype is designed exclusively for existing multi-story residential buildings up to 9 floors (approximately 25m), which narrows its scope of application. However, it can be coupled with new buildings or those with different uses at the architect's discretion, with the understanding that it does not guarantee compliance with certain design intentions, such as affordability (low costs) or NZEB or PEB level achievement.

Another limitation is its time frame (1961–2000), which excludes a considerable number of buildings from its application range. However, we intend to expand the prototype to include other time periods and building typologies once the current version has been successfully developed and tested.

Furthermore, the X-TEND coupling mechanism will be limited to systems based on precast concrete structures and brick masonry external walls, as these were the most widely used building systems in Lisbon and Warsaw from 1961 to 2000 for residential buildings. Following the success of the current X-TEND prototype version, we intend to design coupling mechanisms for other building systems.

Ensuring compatibility between all design intentions and goals poses a real challenge. The use of eco-friendly materials, cost-effective design, and the guarantee of structural and energy performance are envisioned as the most demanding aspects. We anticipate that the process of achieving compatibility and fine-tuning will be lengthy and resource demanding. Additionally, ensuring compatibility between the physical and virtual prototypes may present hurdles, particularly in gaining acceptance from architects and designers, which will probably require a robust dissemination campaign.

As X-TEND prototype aims to adopt sustainable and green construction practices, the lack of European-level certification for most recent eco- and bio-materials, especially in terms of fireproofing, can be an obstacle to the project's success. Given our commitment to ensuring that X-TEND complies with building codes in select countries, addressing this issue is of utmost importance.

We also foresee challenges during its construction and implementation phase that vary depending on location. Since it involves coupling an architectural element with an existing building, it requires the support and endorsement of both local authorities and the building's residents. Overcoming people's scepticism towards new technologies will need an effective communication and promotion campaign that highlights the benefits of X-TEND for users, mostly around the potential reduction in energy costs and readiness for new pandemic outbreaks.

Nevertheless, the purpose of testing its implementation in two distinct locations (Lisbon and Warsaw) is precisely to identify the obstacles unique to those regions and develop an "adapt-to-context" strategy to tackle the observed variations.

Given the large number of buildings suitable for X-TEND prototype coupling, we foresee challenges in securing funding for a larger scale operation. These challenges can be overcome by effectively demonstrating the benefits in all its aspects and gather broader support. On the other hand, the substantial number of buildings without outdoor private spaces underscores the project's relevance and necessity.

Lastly, the prototype's adaptability and transferability, coupled with open-source design, aim to overcome contextual challenges for widespread adoption. Despite significant obstacles, the RP demonstrates a holistic approach to developing sustainable and energy-efficient building solutions for the future.

6. Conclusion

This study delves on the issue of inadequate or non-existent private outdoor spaces in multi-story residential buildings and its adverse effects, which became evident during the COVID-19 pandemic lockdowns. To address this issue and embrace the new paradigm in balcony design, we present a currently undergoing RP consisting of a balcony system prototype named "X-TEND", which expands living spaces outdoors.

Grounded on a LAM approach, the X-TEND prototype RP envisions the development of both a physical and digital prototype, representing a lightweight, modular, permeable, adjustable, and easily dismountable exoskeletal structure that can be integrated into existing building façade(s). Apart from the extension of the living space, its primary objective is to serve as the cornerstone of an energy retrofit operation, transforming existing buildings into NZEBs or PEBSs, while simultaneously enhancing indoor environmental conditions. X-TEND prototype is grounded by a set of intentions and goals (Figure 4) and its potential extends beyond the architectural scope, inspiring interdisciplinary collaborations in fields such as transportation, urban planning, and renewable energy technologies.

The current RP will inevitably face a series of limitations and challenges. On the limitation side, we foresee the restricted scope of application, centred on multi-story residential buildings of up to 9 floors, and the narrow timeframe (1961–2000). On the challenges side, the most prominent are the compatibility between diverse design goals and intentions, material certification issues, funding constraints, and the complexities of construction and implementation of a structure of this scale.

From our perspective, the X-TEND prototype has the potential to impact the European housing landscape by addressing social housing issues and contributing to economic growth and post-pandemic recovery. Moreover, it aligns with six UN SDGs by incorporating sustainable design principles, aiming to reduce energy consumption, enhance indoor air quality and improve user comfort.

In summary, the X-TEND prototype represents a step forward towards the creation of more resilient and sustainable cities with the potential to improve living conditions and foster a sense of community among urban populations.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT 3.5 in order to improve the writing process, namely, readability and language. After using this tool, the author reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Conflict of interest

The authors declare no conflict of interest.

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