Post-Occupancy Evaluation in Apartments Using a Digital Tool: A Comparative Analysis of Application Methods

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Abstract
The construction industry accounts for over one-third of global greenhouse gas emissions. Brazilian vertical housing developments often fail to meet environmental and thermal comfort standards, resulting in a growing reliance on artificial climate control to compensate for design flaws. Given this situation, this article presents the results of applying the Webapp MEU APÊ, developed by [MORA] research group at FAUeD/UFU as an instrument for Post-Occupancy Evaluation (POE). The aim of the study was to investigate the environmental quality of apartments and to identify the role of residents in reducing environmental impacts. The study analyses the application of MEU APÊ in three distinct phases in Uberlândia (MG): usability testing (11 personas), on-site testing (50 residential units, including temperature and humidity measurements with digital thermo-hygrometers in 10 units) and on-site testing (150 residents). The study adopts a hypothetical-deductive approach combined with Design Science Research (DSR). The results revealed that residents' thermal satisfaction is largely "artificial," since their well-being is made possible by the intensive use of climate control devices (air conditioning and fans) - which masks the buildings' poor bioclimatic performance and the lack of passive strategies. Although participants demonstrate high individual awareness regarding energy-saving habits and waste disposal, these actions are limited by systemic barriers, such as the absence of renewable energy systems and the prevalence of collective water metering. This paper concludes that MEU APÊ WebApp effectively fulfilled its role in diagnosing environmental quality and mapping user behavior, proving that digital tools can accurately identify domestic environmental impacts. Thereby it can provide a verified methodology to guide future user-centered building performance evaluation.
Keywords: *post-occupancy evaluation; apartment building; technological innovation; digital interfaces; environmental quality.*

Resumo
A indústria da construção civil é responsável por mais de um terço das emissões globais de gases de efeito estufa. No Brasil, os empreendimentos habitacionais verticais frequentemente falham em atender aos padrões ambientais e de conforto térmico, resultando em uma crescente dependência da climatização artificial para compensar falhas de projeto. Diante desse cenário, este artigo apresenta os resultados da aplicação do WebApp MEU APÊ, desenvolvida pelo grupo de pesquisa [MORA] da FAUeD/UFU, como instrumento de Avaliação Pós-Ocupação (APO). O objetivo do estudo foi investigar a qualidade ambiental dos apartamentos e identificar o papel dos moradores na redução dos impactos ambientais. O estudo analisa a aplicação do MEU APÊ em três fases distintas em Uberlândia (MG): teste de usabilidade (11 personas), teste in loco (50 unidades residenciais, incluindo medições de temperatura e umidade com termo-higrômetros digitais em 10 unidades) e teste in loco (150 moradores). A pesquisa adota uma abordagem hipotético-dedutiva combinada com a Design Science Research (DSR). Os resultados revelaram que a satisfação térmica dos moradores é, em grande parte, "artificial", visto que o bem-estar é viabilizado pelo uso intensivo de climatização artificial (ar-condicionado e ventiladores) – o que mascara o baixo desempenho bioclimático dos edifícios e a ausência de estratégias passivas. Embora os participantes demonstrem alta conscientização individual a respeito de hábitos de economia de energia e descarte de resíduos, essas ações são limitadas por barreiras sistêmicas, como a ausência de sistemas de energia renovável e a prevalência da medição coletiva de água. Conclui-se que o MEU APÊ cumpriu com eficácia o seu papel no diagnóstico da qualidade ambiental e no mapeamento do comportamento do usuário, provando que ferramentas digitais

podem identificar com precisão os impactos ambientais domésticos. Dessa forma, consolida uma metodologia adequada para nortear futuras avaliações de desempenho de edifícios, centradas no usuário.
Palavras-chave: *avaliação pós-ocupação; edifício de apartamento; inovação tecnológica; interfaces digitais; qualidade ambiental.*

Resumen
La industria de la construcción representa más de un tercio de las emisiones globales de gases de efecto invernadero. En Brasil, los desarrollos de vivienda vertical a menudo no cumplen con los estándares ambientales y de confort térmico, lo que resulta en una creciente dependencia del control climático artificial para compensar las fallas de diseño. Ante esta situación, este artículo presenta los resultados de la aplicación de la herramienta WebApp MEU APÊ, desarrollada por el grupo de investigación [MORA] en la FAUeD/UFU, como instrumento de Evaluación Post-Ocupación (EPO). El objetivo del estudio fue investigar la calidad ambiental de los apartamentos e identificar el papel de los residentes en la reducción de los impactos ambientales. El estudio analiza la aplicación de MEU APÊ en tres fases distintas en Uberlândia (MG): prueba de usabilidad (11 personas), prueba in situ (50 unidades residenciales, incluyendo mediciones de temperatura y humedad com termo-higrómetros digitales en 10 unidades) y prueba online (150 residentes). El estudio adopta un enfoque hipotético-deductivo combinado con la Design Science Research (DSR). Los resultados revelaron que la satisfacción térmica de los residentes é, en gran medida, "artificial", ya que su bienestar es viable gracias al uso intensivo de la climatización (aire acondicionado y ventiladores), lo cual enmascara el bajo rendimiento bioclimático de los edificios y la falta de estrategias pasivas. Aunque los participantes demuestran una alta conciencia individual respecto a los hábitos de ahorro de energía y la eliminación de residuos, estas acciones se ven limitadas por barreras sistémicas, como la ausencia de sistemas de energía renovable y la prevalencia de la medición colectiva del agua. Se concluye que la WebApp MEU APÊ cumplió eficazmente su función en el diagnóstico de la calidad ambiental y el mapeo del comportamiento del usuario, demostrando que las herramientas digitales pueden identificar con precisión los impactos ambientales domésticos. De este modo, proporciona una metodología verificada para orientar futuras evaluaciones de desempeño de los edifícios, centradas en el usuario.
Palabras-clave: *evaluación post-ocupación; edificio de apartamentos; innovación tecnológica; interfaces digitales; calidad ambiental.*

Introduction

The construction industry is one of the sectors with the greatest environmental impact, both due to its high consumption of natural resources and the emissions associated with construction processes. As a whole, Civil Construction is responsible for more than one-third of global greenhouse gas emissions (UNEP, 2023). As products of construction processes, housing directly influences residents' quality of life; however, many units fail to meet the basic principles of habitability and environmental and spatial quality (Stevenson and Leaman, 2010; Mallory-Hill, Preiser and Watson 2012; Villa et al., 2022). Therefore, there is a pressing need to improve housing design strategies, based on the relationship between form and function, as well as considering the environmental quality of the built complexes and the habits of the residents (Villa, Bruno and Santos, 2020; Elsayed et al., 2023).

Furthermore, the life cycle of buildings contributes to long-term environmental imbalance. Largely due to the prevalence of inefficient construction solutions, the operational maintenance of these buildings requires a major use of fossil fuel energy sources (IEA; UNEP, 2025). This dependence resulted in 9.8 $GtCO_2$ emissions in 2023, exclusively in emissions destined for energy generation for building operation (IEA; UNEP, 2025). In the Brazilian context, there is a growing trend in the consumption of artificial air conditioning in buildings. This phenomenon is related to changes in the global climate system, to the increase in the population's purchasing power and to the continuous construction of buildings unsuitable for their local climate (Saramago, 2023). Globally, the demand for air conditioning experienced an increase of over 33% between 2010 and 2018, with a particularly pronounced impact in regions with predominantly hot climates, such as Brazil (IEA; UN, 2019).

Furthermore, housing programs, such as Minha Casa Minha Vida (PMCMV), disseminates problematic verticalization models in several aspects. For example, the design of these units has remained largely unchanged for decades, limited only to technical or constructive variations, without any effective questioning of the articulation and function of living spaces (Villa, 2020). Analysis of the units offered demonstrates that they respond in a limited way to the residents' demands, since requirements for comfort, efficiency, functionality, and privacy are met only at minimum levels, especially in smaller floor plans, as shown in post-occupancy evaluation studies (Reis and Lay, 2002; Granja et al., 2009; Villa, 2010; Villa et al., 2013). The main sources of dissatisfaction identified relate to the shrinking dimensions of the rooms, excessive compartmentalization, and the low quality of the materials used. Regarding environmental awareness, it is clear that the involvement of users in environmental preservation is still incipient. While basic actions, that do not require profound behavioral changes or advanced technologies, show more positive results, practices such as solid waste sorting are not always fully integrated into the residents' routine (Villa et al., 2018).

Given this scenario, the environmental quality of housing has gained increasing prominence in studies at both national and international levels, aligned with and grounded in various sustainable development agendas, both globally and locally (Gonçalves and Bode, 2015; Baker and Steemers, 2019). In this context, Post-Occupancy Evaluation (POE) is consolidating itself as a fundamental field for assessing building performance and providing feedback to the design process (Reis and Lay, 2002; Villa, 2010). In addition, the integration of digital platforms into Post-Occupancy Evaluation (POE) framework has emerged as a disruptive approach to mapping environmental performance, yet its theoretical foundation requires a more critical evaluation regarding data reliability and occupant behavior. While traditional POE methods often suffer from low scalability, digital tools streamline large-scale data collection; however, they also risk oversimplifying the complex thermodynamic and psychological factors governing indoor comfort.

These findings reinforce the gap between user perception and actual building performance, a phenomenon widely discussed in post-occupancy evaluation literature. Studies demonstrate that occupants frequently express high satisfaction in macro-environments that sensors label as substandard or inefficient. This divergence between metric-driven sensor data and human perception occurs because occupant satisfaction is not a purely mechanical or deterministic process captured by physical telemetry (Keeling, Clements-Croome and Lukic, 2015). As established by adaptive comfort models (De Dear and Brager, 1998), intangible variables – such as perceived personal control, psychological expectations, and spatial design – frequently compensate for thermal, acoustic, or air quality conditions that sensors categorize as substandard or inefficient (Frontczak et al., 2012; Moezzi and Goins, 2011). Therefore, a critical digital POE must look beyond raw satisfaction metrics, establishing strict triangulations between user feedback, spatial design metrics, and microclimatic telemetry.

Interfaces with IoT, sensors, and interactive applications have enabled greater reach, lower operational costs, and greater user engagement, transforming them into active protagonists in reflecting on their own habits (Villa, Burigo and Saramago, 2023). In this context, many investigations have incorporated new information and communication technologies, developing interfaces and solutions that are both user-friendly and intuitive. This approach allows studies to reach the population more effectively, enhancing their educational and collaborative character (Newton, Carnemolla and Darcy, 2023; Villa and Ornstein, 2021). Thus, the use of these technologies, together with the interactivity provided by digital interfaces, intensifies user interest, which is fundamental for obtaining data with greater precision and reliability (Villa, Bruno and Santos, 2020; Villa et al., 2023). Reviews on post-occupancy evaluation (POE) practices in residential buildings highlight the urgency of developing more consistent and integrated methods, capable of standardizing data collection, in order to allow comparability and replicability (Elsayed et al., 2023).

Considering the above, the [MORA] Housing research group, from the Faculty of Architecture, Urbanism and Design of the Federal University of Uberlândia (FAUeD/UFU), dedicates to improving methodological procedures for post-occupancy evaluation, specifically focused on the housing environment (Ono et al., 2018; Villa and Ornstein, 2013). Within this line of research, projects previously developed by the group stand out, such as "HABITAR VERTICAL" (Villa et al., 2018) and "COMO VOCÊ MORA" (Villa, Bruno and Santos, 2020). These initiatives sought, through the methodological application of post-occupancy evaluation instruments and tools, to construct a qualitative analysis of housing spaces in various typologies in Brazil, both horizontal and vertical. Furthermore, these projects have contributed to the creation of a robust database that serves as a basis and feeds the group's new research proposals.

More recently, in the context of digital transformation, the MORA] Housing Research group developed the APO Digital System 1: a product of the research entitled "[APO DIGITAL SYSTEM] Digital interfaces for post-occupancy evaluation of environmental quality in housing". One of its main artifacts, the MEU APÊ WebApp, was designed to investigate the environmental quality of apartments through multiple dimensions (physical, behavioral, and environmental) and to stimulate residents' self-reflection on their daily habits of consumption, disposal, and adaptations to the space. From this perspective, the project continued with the APO Digital System 2, under development in the research entitled "[APO DIGITAL SYSTEM] Dissemination and improvement of digital interfaces for post-occupancy evaluation of environmental quality in housing". This other project focuses on the improvement and implementation of technologies such as Artificial Intelligence (AI) and the Internet of Things (IoT)[1]. The attributes evaluated by MEU APÊ are: energy and energy efficiency, transport and carbon emissions, water efficiency and

[1] The results of both projetcs can be found at: https://apodigital.wixsite.com/pesquisa.

consumption, waste and disposal, thermal and lighting comfort. It has a graphical interface based on UX/UI Design, IoT features and GPS information sensors and is available on the internet (https://app-mora.facom.ufu.br/evaluation/meuape).

Methods

To achieve the proposed goals and to develop and improve the artifact, the hypothetical-deductive method based on Design Science Research (DSR) was adopted, following the approach proposed by Dresch, Lacerda and Antunes Júnior (2015). Thus, based on the framework developed by these authors, and considering adaptations aligned with the specific goals of this study, the research was structured in ten (10) sequential steps: (i) problem identification; (ii) systematic literature review; (iii) identification of artifacts and of categories of problems; (iv) proposition of artifacts for problem solving; (v) artifact design; (vi) artifact development; (vii) artifact evaluation; (viii) explanation of learnings and conclusion; (ix) generalization to a class of problems and communication of results; and, finally, (x) application of heuristics. This study was submitted to and approved by the Research Ethics Committee Involving Human Beings at the Federal University of Uberlândia (CEP/UFU), under protocol number 69517821.6.0000.5152 – in compliance with Brazilian regulatory guidelines for research involving human subjects. All participants were fully informed about the study's goals and procedures. Data collection only continued after they reviewed and signed the Informed Consent Form (ICF).

This article comparatively and critically analyzes the results obtained with the application of the MEU APÊ WebApp in three distinct scenarios. The text is structured around three main axes: (1) description of the development and the structure of the MEU APÊ WebApp; (2) analysis of the results of usability test, onsite and online applications; and (3) critical reflection on the similarities and differences between the different applications methods, considering their repercussions for design practices and public policies on sustainable housing.

Assessment Instrument and Application Methods

The conceptualization and systematization of the post-occupancy evaluation (POE) questionnaire for the MEU APÊ WebApp were grounded in a structured cross-analysis between macro-sustainability frameworks, building performance criteria, and the daily dynamics of domestic life. It was considered the United Nations Sustainable Development Goals (SDGs), specifically SDG 11 (Sustainable Cities and Communities), which mandates inclusive, resilient, and high-quality housing. To integrate the human factor directly into this environmental evaluation, the researchers adapted Maslow's Hierarchy of Human Needs. By projecting these psychological tiers onto practical housing requirements, a baseline matrix of residential resources (water, air, connection, energy, clothing, and food) was established (Villa, Burigo and Saramago, 2025). This theoretical baseline was operationalized by analysing the lifecycle impacts and supply chains of domestic consumption alongside functions codified by national performance standards (such as ABNT NBR 15.575), thereby directly linking everyday routines to resource depletion and waste generation.

Section 1 profile from the user	Section 2 apartment features	Section 3 environmental comfort in housing	Section 4 consumption energy and energy efficiency
Age, gender, education, family income, family type, and how many people live in the apartment.	Apartment type, usable area, floor on which the apartment is located, location and number of buildings in the condominium.	Thermal and lighting comfort, lighting devices and shading systems.	Measurement of consumption of energy and gas, habits involving energy consumption, household appliances, Procel Seal, water heating, renewable energy sources.
Section 5 efficiency and consumption of water	Section 6 waste and habits of discard	Section 7 specific habits	Section 8 transport and carbon emissions
Individualized measurement of water consumption, habits involving water consumption, water reuse systems.	Separation of waste, frequency and quantity of waste, selective waste collection, discard of specific materials (oil, medicines, electronic devices, batteries and clothing).	Delivery, online shopping, working from home, vegetation in the apartment.	Mobility, means of transport used for certain distances, reasons for choosing this mode of transport.

Table 1
Attributes evaluated by the MEU APÊ artifact. Source: the authors, 2026.

To ensure practical relevance and prevent technological barriers from distorting diagnostics, these variables were structured into three main overarching sections: Profile and Spatial Characteristics, Comfort Satisfaction and Environmental Adequacy. These main sections are systematically operationalized through eight progressive sessions that merge technical data telemetry with user-centred environmental feedbacks. This systematic progression allows the MEU APÊ platform to utilize built-in interactive UX/UI elements, IoT capability, and GPS sensors to diagnose environmental quality under two distinct pillars: *Environmental Comfort* (thermal and lighting attributes) and *Environmental Adequacy* (water, energy, carbon emissions, and waste indicators). Crucially, the practical relevance of this eight-stage architecture lies in its dual-purpose execution: while users provide researchers with highly disaggregated data on resource consume, the interface dynamically triggers educational feedback (screens that display information about different concepts) and warning screens (about environmentally inappropriate habits). These feedbacks turn the diagnostic process into an active tool for user self-reflection, guiding occupants to reduce domestic impacts and optimize resource conservation in real time (Villa, Burigo and Saramago, 2025).

The structure (Table 1) of the Webapp covers aspects such the sociodemographic profile and physical characteristics of the unit to the assessment of environmental comfort in spaces, considering variables such as ventilation, natural lighting, and shading devices. The instrument investigates energy and water consumption habits, the use of equipment with the Procel Seal, and the presence of renewable energy sources. Additionally, it addresses solid waste management (including composting and disposal of specific types of waste, such as electronics), new post-pandemic dynamics (such as working from home and the use of virtual assistants), and urban mobility patterns.

Usability Test

The strategy of initiating the artifact evaluation process with usability testing is justified by the need to validate the interface before submitting it to larger samples. Its relevance lies in ensuring that design or vocabulary flaws do not compromise the actual POE (Post-Occupancy Evaluation) results. Methodologically, this allows the user's effort to be directed towards reflecting on their experience, not overcoming technological barriers. In this way, based on the results obtained in the usability test, it was possible to identify and implement corrections based on data analysis, in order to address the difficulties and problems pointed out by the users. Thus, the necessary adjustments were selected and organized in this stage, with the aim of optimizing communication and dynamics among the researchers involved.

To assess user comprehension with the artifact and verify its comprehension and usability, the System Usability Scale (SUS) and SURE (Smartphone Usability Questionnaire) were studied and adapted according

SUS (System Usability Scale)
I think that I would like to use this system frequently
I found the system unnecessarily complex
I thought the system was easy to use
I think that I would need the support of a technical person to be able to use this system
I found the various functions in the system were well integrated
I thought there was too much inconsistency in this system
I would imagine that most people would learn to use this system very quickly
I found the system very cumbersome to use
I felt very confident using the system
I needed to learn a lot of things before I could get going with this system

Table 2
SUS' Questionnaire. Source: Brooke (1996), adapted by the authors, 2026.

to the goals of this research. The SUS method (Table 2), a simple and well-known usability evaluation approach considers three main evaluation criteria (effectiveness, efficiency, and satisfaction), which were incorporated into three phases of the test: functionality, application, and design (Brooke, 1996), as shown in Table 4. In addition, the SURE questionnaire (Table 3) served as a conceptual basis for developing the usability questions incorporated into the evaluation categories (Gresse Von Wangenheim et al., 2014). This approach provided a more comprehensive and detailed analysis, since the SURE method was built focusing on the smartphone interfaces, which are the main tools addressed in this study. This process resulted in a new evaluation approach consisting of a questionnaire with 25 statements, containing 5 response options, ranging from "Strongly Disagree" (1 point) to "Strongly Agree" (5 points). Therefore, the questionnaire allowed us to understand the effort required to complete tasks, as well as to evaluate the level of user satisfaction during the experience (Table 4).

Before applying the questionnaire, personas with diverse profiles were defined, whose characteristics could influence the ability and ways of using the artifact. Thus, the criteria used for selection included: age range, education level, profession, work model, family profile, and affinity with WebApps tools, as shown in Table 5. Based on these criteria, the availability of volunteers, and strategic combinations of characteristics, the usability test was conducted with 11 personas, as shown in Table 6.

The subsamples were delimited based on a purposive sampling strategy designed to ensure qualitative representation across all predetermined user profiles and

SURE (Smartphone Usability Questionnaire)	
I found it easy to enter data into these apps.	When I make a mistake, it is easy to correct it.
I found the help/tips provided by the app useful.	It was easy to find the information I needed.
I felt in control while using this app.	I considered the time required to complete the tasks appropriate.
It was easy to learn how to use this app.	The sequence of actions in the app corresponds to the way I normally would perform tasks. For example, the order of the buttons, data fields, etc.
It is easy to do what I want using this app.	It was easy to navigate through the app's menus and screens.
The app meets my needs.	I would recommend this app to other people.
Even in a hurry, I would be able to perform tasks using this app.	I found the app consistent. For example, all functions can be performed in a similar way.
It is easy to remember how to perform tasks in this app.	I would use this app frequently.
The organization of menus and actions commands (such as buttons and links) is logical, allowing them to be easily found on the screen.	I was able to complete the tasks successfully using this app.
I enjoyed using this app.	The app provides all the necessary information to complete the tasks in a clear and untestable way.
I found the app very complicated to use	The symbols and icons are clear and intuitive.
I found the texts easy to read.	I found the app unnecessarily complex. I needed to remember, search or think too much in order to complete the tasks.
The terminology used in texts, labels, titles, etc., is easy to understand.	I would need support from another person to use this app.
I felt comfortable using this app.	The app behaved as I expected.
I found using this app frustrating.	I found the various functions of the app well integrated.
I felt very confident using this app.	

Table 3 | SURE Questionnaire. Source: Gresse Von Wangrnheim et al., 2014

Functionality	Application	Design
I found the WebApp application easy to use.	I was bothered by the time it took me to use the WebApp application.	I found the WebApp's interface/ design to be pleasing.
I had problems with the language and vocabulary of the WebApp application.	I felt represented by the profile descriptions presented.	I found that the images and icons share a standardization (style and size).
All the buttons in the WebApp application worked correctly.	I would imagine that most people would learn how to use this WebApp application quickly.	I found that the images and icons in the WebApp application helped with my experience.
I think I would need technical support to use this WebApp application.	I think I would like to use this WebApp application frequently.	I found that the icons in the “environmental comfort” section were helpful in my experience.
I found that several functions of this WebApp application were well integrated.	I felt very confident using this WebApp application.	I found that the “ info “ icon helped with my experience.
I felt there was a lot of inconsistency in this WebApp application.	I learned something new using the WebApp application.	The colors in the WebApp application are satisfactory.
I was able to easily enter my data into the WebApp application.	I felt satisfied using the WebApp application.	The WebApp application format is satisfactory.
The “enable camera” function worked correctly.	I am interested in the content of the WebApp application and the information it provides me.	The sequence of screens in the WebApp application is good and makes sense.
		The “activate my location” function worked correctly.

Table 4 | Statements used in usability testing. Source: the authors, 2026.

<table>
<tr><th>Age</th><th>Education</th><th>Profession</th><th>Working Model</th><th>Family Profile</th><th>Affinity With App</th></tr>
<tr><td>18-24</td><td>Elementary Education</td><td>Related to Architecture / Civil Engineering</td><td>In person</td><td>Nuclear</td><td>High</td></tr>
<tr><td>25-40</td><td>High School</td><td>Related to the Technologies</td><td>Hybrid</td><td>Mononuclear</td><td>Average</td></tr>
<tr><td>41-55</td><td rowspan="3">Higher education</td><td rowspan="3">Unrelated to Architecture, Engineering or Technology</td><td>Remote</td><td>Alone</td><td rowspan="3">Low</td></tr>
<tr><td>56-65</td><td rowspan="2">Retiree</td><td rowspan="2">Cohabitation</td></tr>
<tr><td>>65</td></tr>
</table>

Table 5
Criteria for selecting personas. Source: the authors, 2026.

Table 6
Defined personas. Source: the authors, 2026.

behavioral characteristics identified in the research. The demographic profile of the participants predominantly consisted of young adults[2]. Rather than targeting a statistically uniform age distribution, the sample size was dictated by the strict requirement to have at least one user representing each combination of variables investigated, a condition that was fully satisfied with the selected group.

[2] Just a single participant aged 25 to 40. This specific age representation was restricted to one individual because, during the recruitment process, only one candidate within this age bracket was found to meet the full matrix of architectural, socio-demographic, and behavioral criteria required for the subsamples.

Regarding the Usability Test, the results (Table 7) show that, in the first section, dedicated to evaluating functionality, the artifact presented the greatest discrepancy between responses, registering an average of 2.98 points. This variation was mainly related to aspects such as comprehension and usage time of the WebApp: while some participants performed the proposed tasks without difficulty, others reported greater complexity in achieving the same task. In the second

Questions	Responses				
	Totally Disagree	Partially Disagree	Neither Agree Nor Disagre	Partially Agree	Totally Agree
I found the app easy to use.	0% (0/11)	0% (0/11)	0% (0/11)	0% (0/11)	100% (11/11)
I had no problems with the language and vocabulary of the app.	0% (0/11)	0% (0/11)	0% (0/11)	0% (0/11)	100% (11/11)
I wasn't bothered by the time it took me to use the app.	9.09% (1/11)	18.18% (2/11)	18.18% (2/11)	27.27% (3/11)	27.27% (3/11)
I felt represented by the profile options presented.	0% (0/11)	0% (0/11)	9.09% (1/11)	18.18% (2/11)	72.72% (8/11)
I would not need technical support to use this app.	9.09% (1/11)	9.09% (1/11)	0% (0/11)	0% (0/11)	81.81% (9/11)
I thought several functions of this app were well integrated.	9.09% (1/11)	0% (0/11)	9.09% (1/11)	9.09% (1/11)	72.72% (8/11)
I didn't find any inconsistencies in this app.	18.18% (2/11)	9.09% (1/11)	18.18% (2/11)	0% (0/11)	54.54% (6/11)
I think people would learn how to use this app quickly.	0% (0/11)	0% (0/11)	0% (0/11)	18.18% (2/11)	81.81% (9/11)
I would like to use this app frequently.	18.18% (2/11)	18.18% (2/11)	9.09% (1/11)	27.27% (3/11)	27.27% (3/11)
I felt confident using this app.	0% (0/11)	0% (0/11)	9.09% (1/11)	36.36% (4/11)	54.54% (6/11)
I learned something new using the app.	0% (0/11)	0% (0/11)	18.18% (2/11)	18.18% (2/11)	63.63% (7/11)
I felt satisfied using the app.	9.09% (1/11)	0% (0/11)	9.09% (1/11)	18.18% (2/11)	63.63% (7/11)
I felt interested in the content and the information in the app.	0% (0/11)	9.09% (1/11)	0% (0/11)	18.18% (2/11)	72.72% (8/11)
I found the app's interface pleasant.	0% (0/11)	0% (0/11)	9.09% (1/11)	9.09% (1/11)	81.81% (9/11)
I thought the images and icons had standardization.	0% (0/11)	0% (0/11)	0% (0/11)	0% (0/11)	100% (11/11)
I thought the comfort section icons helped my experience.	0% (0/11)	9.09% (1/11)	0% (0/11)	9.09% (1/11)	81.81% (9/11)
I thought the infographic helped my experience.	9.09% (1/11)	9.09% (1/11)	9.09% (1/11)	9.09% (1/11)	63.63% (7/11)
The app's colors are satisfactory.	9.09% (1/11)	0% (0/11)	9.09% (1/11)	0% (0/11)	81.81% (9/11)
The app's format is satisfactory.	0% (0/11)	0% (0/11)	0% (0/11)	0% (0/11)	100% (11/11)
The app's screen-sequence is good.	0% (0/11)	18.18% (2/11)	0% (0/11)	9.09% (1/11)	72.72% (8/11)

Table 7
Results of the usability test of the MEU APÊ WebApp tool. Source: Burigo and Saramago (2025), modified by the authors, 2026.

part of the test, which evaluated the application of the artifact, a high level of satisfaction was observed among users, with an average of 4.51 points. This result reflected not only the level of user confidence and engagement, but also the quality and accessibility of the information presented on technical terms – such as the ability to understand the specific vocabulary from the descriptions of the WebApp. Finally, in the final phase, which evaluated the design of the WebApp, the artifact performed well, with an average of 4.5 points. However, some specific improvements were identified as necessary, since certain images and icons caused confusion, hindering users' understanding of some screens. Additionally, the difficulties reported by participants are considered to have influenced the discrepancy in scores observed in the first section of the test. Overall, however, positive aspects were highlighted, such as learning sustainable habits related to the proper disposal of certain material and equipment, knowledge about the Procel Seal, as well as the relevance of the images for the effective comprehension of the content.

On-site test

After the adjustments provided by the usability test, the application of the MEU APÊ artifact began, starting with the definition of a case study (Yin, 2003) that met the following criteria: (i) development composed of housing units with usable areas between 50 m² and 150 m²; (ii) development delivered between 2007 and 2017; (iii) minimum of 30 housing units; (iv) common facilities; and (v) development linked to the Minha Casa, Minha Vida Program (PMCMV), bands 2 and 3. The selected development has four towers (A, B, C and D), with 12 (twelve) floors each and 4 (four) apartments per floor (192 apartments total). The apartments have 3 bedrooms, with 90 or 94 m² (in three towers), or 2 bedrooms, with 61 to 65 m² (in a single tower), as shown in Figure 01. In addition, the complex has leisure areas equipped with a swimming pool, sports courts, barbecue area, playroom, gym, party room, games room, and bathrooms.

In parallel with the use of the WebApp, temperature and relative humidity measurements were taken in 10 (ten) apartments and in the external environment using digital thermo-hygrometers (Figure 2). The objective was to identify variations in air temperature and relative humidity over a week, both inside the housing units and in the external environment. These measurements allowed for a more precise analysis of the thermal performance of the apartments, comparing

Figure 1
Floor plans of the apartments studied project layout. Source: Promotional material, modified by the authors, 2026.

the measured data with the residents' own perceptions of the thermal comfort conditions of the units. This data collection also made it possible to verify whether artificial resources, such as air conditioning equipment, were being used by residents to achieve satisfactory thermal comfort conditions in the evaluated units.

Regarding the environmental monitoring during the on-site phase, microclimatic variables (air temperature and relative humidity) were measured under active and real-use conditions. Artificial climate control systems, such as air conditioning and fans, were permitted to operate normally throughout the measurement period, reflecting the residents' spontaneous adaptation and daily routines. The digital thermo-hygrometers were strategically installed and positioned by the researchers to ensure standardized data collection without interfering with household activities. Residents were requested not to touch or relocate the equipment itself. By documenting the microclimate under typical occupancy behavior, this protocol captured how artificial cooling vectors directly modify internal environmental conditions, providing the empirical basis to contrast objective sensor data against subjective user perception (Saramago et al., 2025).

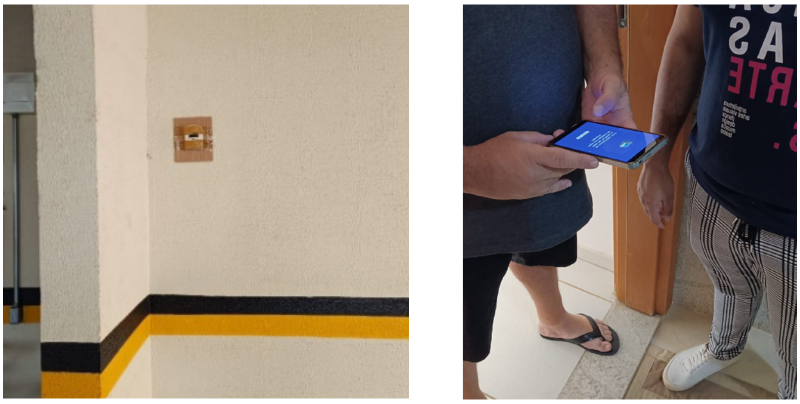

Figure 2
Digital thermo-hygrometers installed on-site[3].
Source: Archive of the research group, 2024.

[3] Digital thermo-hygrometers were installed inside the apartments, as shown in the image on the left, and in the external area (garage), as shown in the image in the center. On the right, a record of the researcher applying the tool with the resident.

After defining the case study and obtaining authorization from the condominium manager, residents were invited to participate in the test through informational posters, individual letters, and announcements in messaging groups. However, due to limited participation in this first stage, it was necessary to adopt new recruitment strategies, including in-person approaches in common areas by student researchers, directly inviting residents to participate in the evaluation. In the initial planning, the parameters for calculating the sample size established a confidence level of 95% and a margin of error of 8%, resulting in a sample of 85 apartments. However, due to difficulties that compromised resident participation, such as low participation, it was decided to redefine the parameters, maintaining the confidence level at 95%, but adjusting the margin of error to 12%, resulting in a final sample of 50 apartments.

In regard of the on-site application, the study revealed a notable homogeneity in the sociodemographic profile of the participants, with 67,3% of them being between 21 and 50 years old. This population exhibits a high level of human and financial capital, with over 93,9% having at least completed high school, and the

PLANNING					
Date	Location	Sampling	Respondents	Objectives	Instruments Used
February/ March 2024	Imperial Residence Condominium	192 apartments Confidence level = 95% Margin of error = 12%	50 apartments	On-site application of the MEU APÊ artifact	Residents' and researchers' mobile devices
February/ March 2024	Imperial Residence Condominium	50 apartments 20% of participating apartments	10 apartments	Temperature and humidity data collection	Digital thermo-hygrometer

Table 8
Planning of On-Site Testing Stages. Source: the authors, 2025.

prevalence of women, who accounted for 55.1% of the participants. The socioeconomic profile of the participants revealed that most of them earn more than three minimum wages. Based on the current Brazilian minimum wage of BRL 1,621.00, this income bracket places the majority of the sample at the upper threshold of Economic Class D and the entry levels of Class C, according to the Brazil Economic Classification Criterion by ABEP (Brazilian Association of Research Companies).

87.8% of residents live in conventional apartments and frequently make functional adaptations. The conversion of single bedrooms to other uses, such as home offices, is an example of this (46,9%). This situation indicates a search for functionality and adaptation of spaces to new contemporary needs. Furthermore, the analysis of environmental comfort reveals one of the study's main conclusions: the high satisfaction of residents ("Good" or "Very Good") coexists with low bioclimatic efficiency of the buildings, making thermal comfort an "artificial" consequence. In the on-site test, the predominantly positive rating for natural ventilation and thermal sensation is associated with the use of cooling equipment. Air conditioning is used frequently in the summer, with temperatures close to the minimum (below 23°C, 6 to 9 hours/day), while external temperature measurements exceeded 35°C, confirming the high thermal load in the environments. In addition, the low adoption of external shading devices, with 88.9% of the on-site participants stating they do not have them, and the fact that most participants do not use passive strategies (such as sunshades or window protective film), suggest that initial design flaws are compensated for high electricity consumption.

Analysis of electricity and water consumption habits in the on-site evaluation reveals a conscious individual effort that is, in part, mitigated by the limitations of condominium infrastructure. Average electricity consumption (301 to 400 kWh/month) is more than doubled the national average (152.2 kWh/month), despite a high awareness of energy conservation (79.6%). Residents adopt habits such as turning off lights and appliances and show a preference for purchasing appliances with the Procel Seal. However, the high energy demand resulting from electric water heating (the only source available for 100% of the participants) and, especially, the use of air conditioning and fans during hot seasons, offsets part of the savings generated by conscious habits. The low prevalence of renewable energy generation systems (87.8% of them have none) represents an opportunity to reduce energy demand. Furthermore, data collected from on-site devices reaffirms the residents' "artificial" thermal satisfaction, given that thermal comfort is achieved through the intensive use of artificial climate control, exceeding 9 hours per day. Thus, the masking of design deficiencies and the lack of effective passive strategies were identified.

Therefore, these findings critically advance the discussion on user perception by introducing the phenomenon of "artificial" thermal satisfaction, a state where occupant well-being is heavily decoupled from the building's intrinsic thermodynamic properties. In this scenario, the poor bioclimatic performance of the architectural design is effectively masked by the intensive, longitudinal operation of active cooling systems, especially air conditioning units. This phenomenon aligns with international literature on thermal adaptation and building resilience (ASHRAE, 2023), which warns that high user satisfaction scores in flawed architectural envelopes are frequently artifacts of high energy consumption rather than indicators of passive architectural quality. By relying on mechanical compensation to mitigate design pathologies (such as inadequate solar orientation or lack of shading devices), occupants inadvertently absorb the operational costs of building inefficiencies. Therefore, the data gathered by the MEU APÊ WebApp demonstrates that apparent user comfort should not be evaluated as an absolute indicator of environmental sustainability, as it conceals a structural dependency on artificial climate control, a phenomenon that directly contradicts net-zero and energy-efficiency paradigms (De Dear et al., 2013).

Regarding water consumption, collective metering represents 100% of the on-site evaluation, which hinders the adoption of more consistent strategies, as awareness of individual consumption is lost. Monthly consumption ranged from 10 to 30 m³, while adherence to water-saving habits was widespread (83.7%), through practices such as quick showers, turning off taps, and reusing water from the washing machine. However, 69.4% of the residents claimed not to have water-saving devices, although on-site observation revealed the presence of dual-flush toilets, indicating a communication failure in the questionnaire. In addition, 73.5% represents the lack of knowledge regarding greywater and rainwater reuse systems, which demonstrates a gap in condominium water management, limiting the impact of individual actions.

Furthermore, solid waste management is a positive aspect of the on-site results, given that the separation between recyclable and non-recyclable waste is a common practice between 87.8% of the participants. This situation is due to the existence of the selective waste collection service in the neighborhood, as well as the separation system offered by the condominium. The disposal of hazardous waste (medicines, electronics, batteries) is carried out correctly at collection points by 86.6% of the residents. The WebApp has also demonstrated educational value by alerting residents who were unaware of the correct disposal methods, encouraging them to adopting new habits. Composting of organic waste remains an incipient practice, with 71.4% of the on-site respondents stating that they do not practice it. This indicates the need for more advanced environmental education campaigns, as well as the incorporation of these practices collectively in vertical housing.

Finally, transportation habits in the on-site evaluation reveal that increasing distances result in a majority shift to motor vehicles (cars and motorcycles), justified by speed and affordability. This finding demonstrates that environmental awareness in waste management does not necessarily translate into sustainable mobility choices, which directly impacts the environment through carbon emissions.

Online Test

After the on-site application, the artifact underwent further adjustments based on user feedback, intending to improve it for the next stage: online application. During the testing phase, the application experienced occasional system errors primarily attributed to the excessive questionnaire length. The system errors were related to navigation and app flow, user interface (such as unresponsive buttons), and textual or graphical inconsistencies that required immediate correction. Therefore, alternatives were analyzed to reduce the questionnaire's length[4]. The result was a more intuitive, efficient, and dynamic artifact.

[4] The questionnaire was optimized for the online application to enhance user engagement and mitigate digital dropout rates. A group of questions originally distributed across individual screens in the on-site version were structurally grouped into a single interface. This consolidation reduced the total number of screens from 163 to 113 in the online version, strictly preserving the original content, variables, and research goals.

Given these modifications, a new verification stage became necessary to validate whether the objectives proposed with the changes were effectively achieved. To this end, a usability test of the online version of the questionnaire was conducted, directed at members of the research group and invited volunteers. It was then verified that the implemented changes were successful, since the problems identified in the previous stages did not recur during the use of the new version of the WebApp. Finally, the artifact proved ready for the definitive online test, which corresponds to the last planned evaluation stage. Figure 3 illustrates some screens of the MEU APÊ, in this last stage.

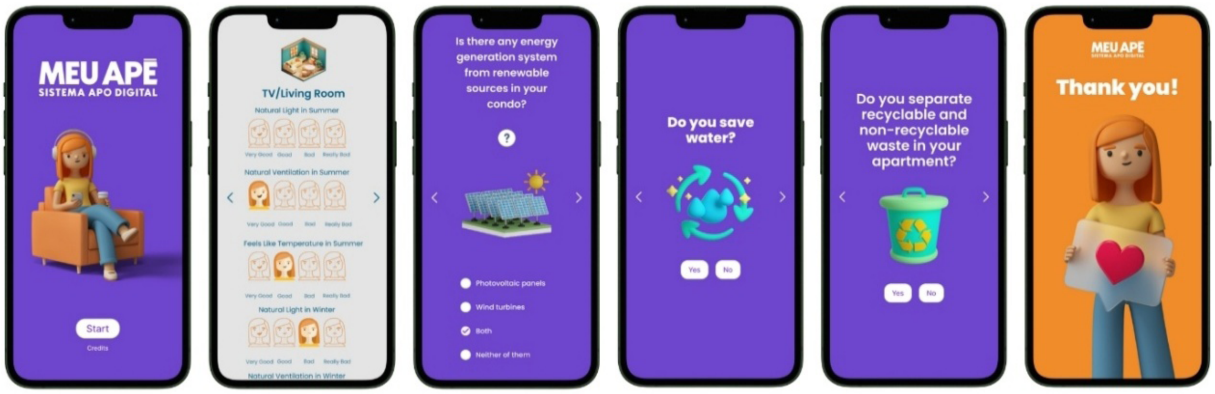

Figure 3
Screenshots of the MEU APÊ artifact. Source: the authors, 2026.

Initially, the dissemination of the research for the online test occurred through social media, such as Instagram and WhatsApp, and by requesting the UFU Communication channel (Comunica UFU) to promote the MEU APÊ WebApp to the academic community. A live interview was also conducted on TV Integração, an affiliate of TV Globo. Finally, A4-sized printed posters were distributed and posted in various locations, such as the university campus and apartment buildings. The sample size for the online survey was determined using a standard statistical formula for finite populations, considering a total universe of 67.196 apartment units in the city of Uberlândia (IBGE, 2022). Based on a 95% confidence level and an 8% margin of error, the equation established a minimum required sample of 150 participating apartments, a target that was fully achieved during the online data collection phase.

About the online test, the results presented similarities to the on-site evaluation, especially according to the sociodemographic profile of the participants – which reinforces the idea that the sample represents a specific segment of the vertical real estate market in Uberlândia. The sample is predominantly young, with 71.6% representing the age range between 21 and 40 years old. Regarding the level of human and financial capital, 97.3% of them had at least completed high school and 62.8% earned more than three minimum wages. The prevalence of women was even stronger in the online test, comprising 74.3% of the participants. In terms of housing, the dominant typology was also the conventional apartment (96.6% of the evaluation), with the difference that only 31.8% of the apartments underwent adaptations.

Moreover, the results of the online test regarding the analysis of environmental comfort confirm that the perception of comfort is predominantly positive in all rooms, but the high frequency of use of air conditioning (6 to 9 hours/day in summer) and fans (3 to 9 hours/day in summer) is the main strategy adopted to maintain satisfaction. The reliance on air conditioning and fans demonstrates that comfort is achieved through significant energy consumption, rather than through architectural efficiency. In addition, 38.3% of the online participants stated that they do not have external shading devices, a much lower percentage than seen on-site. Most of them do not use passive strategies, such as sunshades or window protective film, which also suggests initial design flaws that are compensated for high electricity consumption.

According to the electricity and water consumption habits, electricity consumption also remains high, as seen on-site, with an average of 101 to 300 kWh/month, despite 83.1% of the participants being aware of energy conservation techniques. Furthermore, the high energy demand resulting from electric water heating, which represented 86.9% of those online, and especially the use of air conditioning and fans during summer, offsets part of the savings generated by conscious habits. The use of renewable energy generation systems remains low, with 87.2% of participants claiming that they have none.

In relation to the water consumption section, 78.4% of the residents use collective metering, which confirms the hindrance to the adoption of more consistent strategies, as well as awareness of individual consumption. With regard to the monthly consumption of the online participants, there is a slight variation, with a range of 21 to 50 m³ of consumption, and a slightly higher percentage of people being aware of water-saving habits (89.2%). Nevertheless, 75% of the participants claimed they do not have water-saving devices. An optimistic view is that less than half of the online participants (48.6%) were unaware of or did not have greywater and rainwater reuse systems.

Regarding solid waste management, 60.8% of the participants practice the separation between recyclable and non-recyclable waste, indicating that the correlation between the condominium's offering and the adoption of the habit is direct. The composting of organic waste still represents an incipient practice, according to the evaluation of 89.9% of the participants, who claimed that they do not practice it.

Lastly, the transportation habits section reveals that, although residents use walking for short distances (up to 3 blocks, 68.2% online), increasing distances result in a majority shift to motor vehicles (cars and motorcycles), justified by speed and affordability. From this perspective, the comparative analysis between on-site and online tests consolidates the understanding that, although the residents have conscious of their individual practices, they are also limited by systemic and infrastructural barriers – since Uberlândia does not have a comprehensive urban mobility policy that favors and promotes the use of lower-impact modes of transport.

Results and Comparative Analysis Between the Applications Methods

The strategic choice of three testing modalities in the research is highlighted, aiming at the articulation and relationship of data to ensure the efficiency of the artifact. While usability test focuses on human-computer interaction, on-site test is relevant because it allows for the correlation between satisfaction with environmental comfort reported by residents and physical data collected by digital thermo-hygrometers. Finally, online test complements the process by testing the robustness of the tool in a broad and remote application scenario. This methodological progression ensures that the results do not reflect only isolated opinions, but a broad set, enabling a more precise diagnosis.

It is noted that the poor bioclimatic performance of buildings was one of the main findings of the WebApp. After all, thermal satisfaction is not a result of spatial and constructive solutions, but rather of the intensive use of artificial cooling systems, which drives the growth of energy consumption. In parallel, condominium infrastructure acts as a bottleneck for sustainability, since collective water metering and the absence of water reuse systems (greywater and rainwater) inhibit individualized consumption control and the adoption of more advanced practices. Furthermore, although solid waste management is effective (separation and proper disposal), driven by the convenience of selective collection, the low adoption of composting and the use of individual modals of transport, indicate that sustainability is not a homogeneous priority in everyday choices.

The study therefore points to the need to intervene in three main areas to promote a more sustainable urban ecosystem: (i) bioclimatic improvement, since it is imperative that the architectural designs of new and future buildings incorporate efficient passive solutions (shading, cross ventilation, thermal insulation) to reduce the thermal load and dependence on air conditioning; (ii) building infrastructure, that is, individual water metering and the implementation of reuse systems in condominiums should be encouraged; and (iii) environmental education and public policies, through community instruction on less common everyday topics, such as organic composting, as well as promoting active mobility and public transport, which allows for the replacement of the individual motor vehicle.

Thematic axis	Indicator Selected	Results On site (N=50)	Results Online (N=150)
Profile Sociodemographic	Predominant age range (21 to 40 years)	67.30%	71.60%
	Education (High school) (complete)	93.90%	97.30%
	Family income above 3 minimum wages	61.30%	62.80%
Typology and Space	Apartment “Conventional” type	87.80%	96.60%
	Room conversion for a home office.	46.90%	31.8%*
Comfort and Energy	Perception of Thermal Comfort (Summer) - “Good/Very Good”	65.70%	59.40%
	Use of air conditioning (6 to 9 hours or more per day)	40.00%	50.00%
	Lack of renewable energy systems	87.80%	87.00%
	Electric water heating (shower)	93.90%	91.30%
Resources Water	Collective (condominium) water metering	100%	78.40%
	Stated habit of saving water	83.70%	89.20%
	Absence of energy-saving devices	73.50%	48.6%
Waste Management	Separation of recyclable/non-recyclable waste	87.80%	60.80%
	It does not compost organic waste.	71.40%	89.90%
Mobility	Use of Car/Motorcycle for distances up to 3 blocks	36.6%	68.20%

Table 9
Results of on-site and online tests of the MEU APÊ WebApp. Source: the authors, 2026.

The comparative analysis (Table 10) between the tests reveals that the efficiency of the MEU APÊ WebApp as a Post-Occupancy Evaluation (POE) tool lies in the complementarity of its stages. While the usability test ensured that the technological barrier did not invalidate the data, the on-site test provided the necessary empirical evidence to prove that the feeling of thermal comfort reported by users is, in fact, an "artificial satisfaction" sustained by high energy consumption. Finally, the online test demonstrated the feasibility of transforming citizens into active sensors of their environment, although community engagement still faces barriers to adoption and socioeconomic disparities. Together, the tests validate the tool as a device for technical diagnosis, as well to raise environmental awareness among residents, since it can promote self-reflection on disposal and consumption habits.

Beyond architectural diagnostics, the deployment of digital POE tools carries profound socio-technical implications for public policy and regulatory frameworks in the construction sector. By converting qualitative

Attribute	Usability Testing (SUS)	On-site Testing (Case Study)	Online Test (Comprehensive)
Objectives	Validate the interface, comprehension, and usability of the artifact before large-scale application.	To correlate the satisfaction reported by residents with physical data (thermal/ humidity) measured by sensors.	To test the robustness of the tool in a remote and diverse application scenario in the city.
Cutout Sample	11 people with diverse profiles in terms of age, education, and technological affinity.	50 apartments in a condominium linked to the PMCMV (bands 2 and 3) in Uberlândia.	150 apartment dwellers in Uberlândia, recruited via social media and the press.
Attributes Evaluated	Functionality, application (vocabulary/trust) and design (interface/icons).	Physical dimensions, environmental comfort, energy/water consumption, waste, transportation, and physical thermal measurements.	Physical, behavioral, and environmental dimensions of the quality of living in apartments.
Strong Aspects	High satisfaction with the design (4.5/5) and educational effectiveness regarding technical terms.	Technical precision in unmasking "artificial satisfaction" through the use of thermohygrometers.	Quantitative scope and validation of the systemic robustness of the digital tool.
Aspects Fragile	Discrepancy in functionality (2.98/5) due to navigation difficulties and usage time.	Low initial participation from residents, requiring a redefinition of the margin of error to 12%.	Excessive length of the questionnaire and occurrence of systemic errors in the initial phases.
Opportunities	Implement UX/UI fixes to avoid confusing variables in POE.	Identify design flaws (lack of bioclimatic strategies) to provide feedback for future projects.	Expand to other typologies and integrate with AI and IoT for real-time monitoring.
Threats	Exclusion of users with low digital literacy if the interface is not simplified.	Distrust or lack of interest from residents in participating in in-person surveys.	Sampling bias, restricting itself to more engaged and connected socioeconomic groups.

Table 10
Comparison between the tests and stages developed. Source: the authors, 2026.

resident feedback into structured, actionable data, these tools can provide empirical guidance for updating building codes and performance standards. However, the operationalization of digital-only evaluation frameworks introduces significant limitations across different social profiles, potentially exacerbating issues of digital exclusion. In developing contexts like Brazil, lower-income demographics often face barriers regarding continuous internet access, hardware compatibility, or digital literacy, which biases sample populations toward highly educated, tech-savvy, and socioeconomically stable groups. Consequently, if housing public policies rely exclusively on data generated via digital applications, there is an inherent risk of silencing the spatial and environmental vulnerabilities of marginalized communities who live in substandard housing. To mitigate this bias, future public housing strategies must incorporate hybrid methodology, ensuring that digital POE innovations do not inadvertently institutionalize a form of algorithmic discrimination in urban planning.

Conclusion and Future Perspectives

Considering the above, the application allows for the systematic collection of empirical data on environmental quality in occupied apartments through resident participation, while simultaneously supporting the identification of critical design flaws to be addressed in future developments. The results obtained from the usability test, on-site and online applications in Uberlândia (MG) confirm that the WebApp is appropriate and functional for assessing housing units in terms of environmental suitability and comfort. Regarding the environmental awareness of the respondents, the sample demonstrated engagement with actions aimed at reducing domestic impacts, though more satisfactory results were concentrated in everyday habits that do not require specialized equipment or profound behavioural modifications. Furthermore, the educational dimension of the MEU APÊ tool was observed in specific, measurable instances, such as the self-reported increase in knowledge regarding the correct disposal of hazardous and solid waste. Finally, physical comfort measurements combined with user responses reinforced the urgent need for proper solar orientation of apartment towers and the implementation of solar protection devices in building openings, crucial feedback elements for improving thermal comfort in future residential designs.

The contributions of this study are evident across several domains. It reinforces the importance of interdisciplinarity among architecture, design, and computer science for developing robust, user-centred digital Post-Occupancy Evaluation (POE) tools. Additionally, the study provides a structured set of empirical data capable of supporting public policy formulation and new construction regulations aimed at building performance efficiency. Notwithstanding these contributions, the research process presented clear limitations, including low initial resident participation in the on-site phase, which necessitated adjusting the sampling error margin, occasional technical data collection failures regarding transportation variables, and an inherent sampling bias that restricted the current evaluation to a more socioeconomically and culturally engaged segment.

Looking to the future, the continuation of this research aims to directly address these limitations by expanding empirical tests to other housing typologies and a broader diversity of socioeconomic profiles. Furthermore, future investigations will focus on deepening the integration of the artifact with Internet of Things (IoT) sensors and Artificial Intelligence (AI) technologies for automated, real-time microclimatic tracking. Crucially, evaluating whether these digital interfaces possess a long-term transformative effect on shifting deeply ingrained sustainable habits will be addressed with closer scrutiny in these future studies, treating behavioural transformation as a key milestone for longitudinal research. The ultimate goal remains to consolidate the Digital APO System as an essential platform for continuous building performance diagnosis and user-centred environmental feedback, actively contributing to a more sustainable urban future.

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