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A sociotechnical approach to users' heritage values and decision-making processes for energy efficiency and thermal comfort in heritage buildings: A pilot study in Mexico City

K S Murillo[1,4], K Fouseki[2] and H Altamirano[3]

[1] UCL Institute for Sustainable Heritage, University College London, London WC1E 6BT, UK
[2] UCL Institute for Sustainable Heritage, University College London, London WC1E 6BT, UK
[3] UCL Institute for Environmental Design and Engineering, University College London, London WC1E 6BT, UK
[4] Corresponding author, ucftkmu@ucl.ac.uk

Abstract. Historic buildings have been gradually considered within energy efficiency practices and renewable energy systems, but the implementation of such measures is more complex for historic buildings. It is fundamental to understand the importance of users in the heritage-energy sector. Thus, energy conservation practices of historic buildings that involve less invasive interventions that could lead to loss of value must be promoted. The paper illustrates how residents of historic buildings in the Historic Centre of Mexico City (World Heritage) make decisions on energy efficiency with the ultimate goal of improving thermal comfort and reducing energy consumption. This study consists of five in-depth semi-structured interviews complemented by monitoring internal environmental conditions such as temperature and relative humidity. The thematic analysis of the interviews was followed by a system dynamics analysis to better understand the changes in decision making over time. The dynamic hypothesis is that heritage values assigned to historic buildings change over time and they drive or prohibit changes in energy efficiency. Moreover, a tension arises over time between the limitations on listed buildings in which making many changes in use and energy efficiency interventions is prevented. Our results show that participants take passive thermal-comfort actions (e.g., wearing more clothes and closing windows) when internal temperatures are low. They oppose major interventions or invasive retrofitting to the building, given the high cost and potential loss of value assigned to their buildings. The changes the users would consider while dealing with uncomfortable internal conditions are small interventions in floors and ceilings; however, they avoid making changes to aspects they consider are important and must be preserved and protected (social and cultural values). Integrating the understanding of users' behaviours toward energy efficiency and heritage values can enhance retrofitting policies and guidelines that help protect and maintain the heritage-built stock.

Keywords – heritage values, user, energy efficiency, thermal comfort, Mexico City.

1. Introduction

Although historic buildings are excluded in most cases from the energy performance of buildings in Europe and worldwide [1],[2],[3],[4],[5],[6], EU-funded research programs revolving around climate change, energy efficiency and heritage have been increasing in recent years. The 'Energy Efficiency for EU Historic Districts' Sustainability (EFFESUS)' and 'Climate for Culture, and Efficient Energy for EU Cultural Heritage (3ENCULT)' are some of the few examples that exist that aim to address the impact of changing climatic conditions on heritage while proposing energy-efficient retrofit solutions that respect the heritage values of historic buildings. In the United Kingdom, technical guidance from Historic England seeks to improve the energy efficiency of historic buildings 'by approaching each building in its entirety' [7]. A historic building should be understood as a part of a socio-cultural organisation (i.e., the values and the communities that inhabit or use it) and the building architectural system (physical elements such as walls, floors, ceilings, structure, windows, doors and stairs), which changes and is subject to users' behaviours and preservation. The programs mentioned above rely on research that aims to integrate new technologies into the built heritage stock. In addition, most legislation does not entail an in-depth discussion of users' values. Fouseki et al. [8] applied a cross-disciplinary method for understanding and integrating heritage values into decision-making to improve the energy performance of the heritage building stock, which inspired the present work. A fundamental condition for developing effective energy policies, standards and guidelines is to understand the significance of the users of the heritage building. This paper presents an investigation of the Historic Centre of Mexico City, which aimed to address the users' decision-making processes for energy efficiency and thermal comfort in a world heritage site. The study focusses on the social and cultural values residents of listed and non-listed buildings attach to their buildings, and which values they prioritise over time during energy efficiency interventions that benefit both the residents involved in the process and energy efficiency policymakers. Numerous management plans have been developed for the Historic Centre of Mexico City (Centro Historico) without much progress. Current plans should highlight the need for better policies and management plans for heritage sites in developing countries that must include sustainability. This work offers new research insights using data obtained on heritage, values, user behaviour and thermal comfort in a world heritage site. Our dynamic hypothesis is that social meaning, spatial structures, heritage values, sustainability preservation and energy efficiency are interconnected and reinforced over time, driving or prohibiting changes in energy efficiency. The present study assumes that the tangible characteristics (e.g., architectural, historic and aesthetic) and sentimental or symbolic aspects of a building (e.g., family attachment) increase the overall value of the residence over time. This change in value determines the building characteristics residents are willing to alter, compromise or maintain to improve the energy performance of the building.

2. The case of Mexico City's historic centre

The Mexican programs for reducing electricity consumption nationwide include the Trust for Thermal Insulation of Housing (FIPATERM) and the Integral Systematic Savings (ASI). Both programs, led by the Secretary of Energy [9]have achieved an estimated reduction of 3,500 GWh and led to 1.5 million fewer tonnes of concentrated CO_2 in the atmosphere [10][11]. Despite this progress and the goals that have been set to retrofit existing buildings, much work remains to be done in Mexico for the heritage sector and its users. The Mexico City historical centre provides an ideal opportunity for researchers to examine how owners and tenants of historic houses in a world heritage city negotiate their decisions on heritage conservation and energy efficiency. The world heritage status imposes certain restrictions upon users regarding what they can and cannot change. It is therefore interesting to examine how residents intervene in this specific context. The existence of social housing (intended for people with limited resources) also makes this region compelling to study. The area comprises 668 blocks that lodge approximately 1500 buildings catalogued with artistic and historical value[12]. Since its declaration as a world heritage site in 1987 [13]the Mexico City historic centre has faced challenges on the social, political, environmental and economic fronts, given its geographic situation and the historic transformation of its social context. Hence, management instruments must be developed given the political and management complexity of the heritage site.

3. Methods and materials

Through the socio-technical method of system dynamics [14],social data (related to residents' attitudes towards heritage values and energy efficiency) were collected, analysed and alongside environmental (relative humidity and temperature) and building condition data (materials and maintenance). The environmental data are related to the environmental impact of decisions on energy consumption and user´s thermal comfort. The social data are associated with the current perceived conditions of the buildings. The study started in October 2018 with the recruitment of participants based on at least one of the following two criteria: they must have lived in the building since the Declaration of World Heritage in 1987, or their building must have belonged to the government-listed building and land use inventory. Subsequently, between December 2018 and January 2019, residents were interviewed in five apartments of buildings. On the same day, environmental monitors for temperature and relative humidity were installed. The housing buildings in this study are part of the local regeneration program of the City Council of Mexico City. The heritage area is occupied in most if it by social housing inhabited by people with limited resources while other buildings that have been conserved and renovated are privilege for commercial uses. The historical buildings preserve the original typology of the architectural unit and are part of the World Heritage Site catalogue (134 residential buildings). The representative sample included one historical monument, one unlisted but protected building apartment and three listed apartment buildings. A historical monument is linked to the history of the nation, and a building is listed or protected because of its historical or artistic value or its age. Their architectural styles range from the 18th to 19th century (predominantly baroque or colonial style), which define each building's construction materials (tepetate, cantera and brick) (Image 1).

Image 1. Architectural styles of buildings included in the final sample

A semi-structured interview was designed and divided into three main parts. The first part included the conditions and values attributed to the buildings by users, the second included thermal comfort perceived by users and the interventions undertaken by the users in terms of thermal comfort and the third included energy efficiency interventions undertaken. All interviews were performed in Spanish and translated to English for analysis afterwards. A total of 52 questions were included in the semi-structured interviews. The question focuses on the interventions they made based on the building's condition as they perceived it (retrofitting and maintenance) in walls, ceilings, floors, windows, ventilation, and heating. Complementary data regarding the buildings' physical conditions were collected and combined with environmental data collected using a thermal imaging camera and environmental monitors (tiny tags). This information was used to compare and contrast people's desired and perceived thermal comfort with the actual interior temperature and humidity. The monitoring was conducted in winter for 28 days during December and January. Monitoring sensors were placed in spaces that were perceived as thermally uncomfortable by users, as identified in the interviews. The interviews were transcribed, and the subsequent data were thematically analysed through NVivo that enabled us to identify the cause-and-effect relationships among factors that affected a certain intervention (or lack thereof). The data were coded in relation to the research question. The first coding resulted in 251 codes that were then processed through axial coding. This process resulted in 12 broader categories, similar to the categorisation of Fouseki et al. 2020 [8]. The cause-and-effect relationships between nodes were identified and recorded on Excel. Table 1 presents the codes grouped into 12 categories

Table 1. Categories and code groups

Category	Codes	Category	Codes
Time	time in the property, changes over time	**Materials**	facades, walls, humidity, porosity
Needs	thermal comfort in winter and summer, perceived thermal comfort	**Practice**	qualified interventions
Feelings	satisfaction, guardianship, family attachment	**Cost**	rent, cost of changes
Value	sentimental, aesthetics, historic, symbolic, originality	**Risk**	earthquakes, humidity, lack of maintenance
Place/ Space	urban context, room size	**Ownership**	owner, tenant
Actions	preventive maintenance, corrective maintenance, thermal comfort actions, ventilation, preservation	**Building type**	listed, not listed

The cause-and-effect relationships were then mapped on Vensim, a commonly employed software for system dynamic analysis (Figure 2). System dynamics is a tool that allows users to understand the interconnections among factors associated with the behaviour of a system. In this case, our 'system' is the decision-making process of residents in historic buildings in energy efficiency and thermal comfort. We used the software Vensim to create a 'causal-loop' diagram which shows how some factors are constantly interconnected, forming a 'reinforcing loop'(R) or negative relationships (B). For instance, the reinforcing loop R1 shows that the more original the façade of the building is, the higher the aesthetic value attributed by the user is. In contrast, the balancing loop shows that the more original features the building has, the more likelihood deterioration occurs; however, users resist changes because they want to retain the original features, creating a balance.

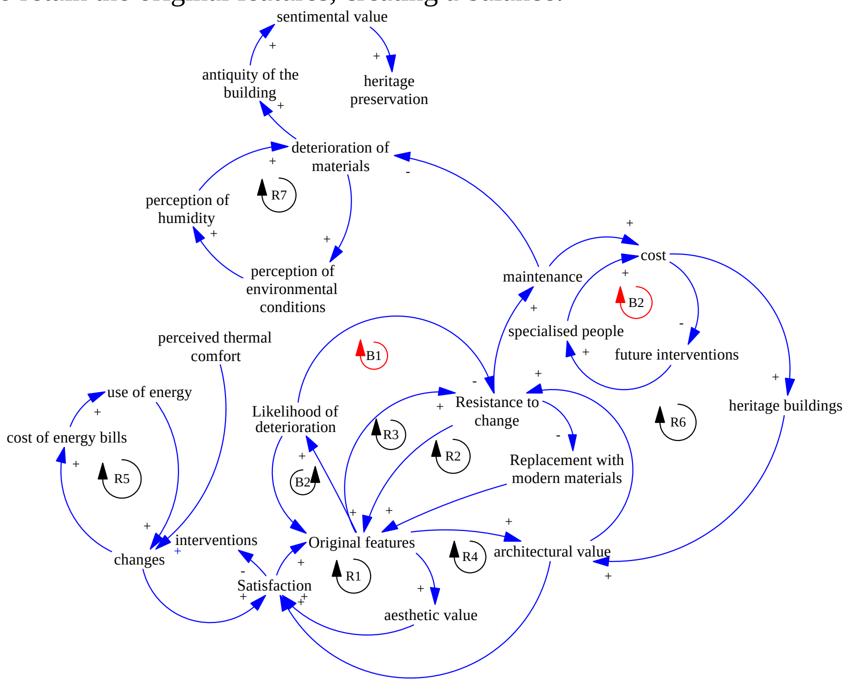

Figure 2. Causal loop diagram created on Vensim that shows relationships between values, interventions and thermal comfort.

4. Results

The findings follow what users' priorities were in terms of heritage values assigned to historic buildings and the interventions implemented to improve thermal comfort. The results also show the tension caused by the limitations imposed on a listed building in which making many changes in use and energy efficiency interventions are prohibited, which affects the process of decision-making over time. The historical value is the primary value associated with properties followed by architectural, aesthetic and symbolic value, which are reinforced over time. The preservation of values is a priority followed by the physical conditions of the building (materials and maintenance needed) and the need of a negotiation between thermal comfort, energy efficiency and heritage conservation.

4.1. Overall heritage values

The analysis illustrates that the original façade reinforces the building's aesthetic value, which in turn enhances the tranquillity of the surrounding space and the overall satisfaction of residents associated with living in the building. This encourages the users to spend more time on the property and strengthens the sentimental value attached with the house. As stated by one of the residents: *'Well, the façade is pretty. The building is beautiful and well-preserved, and it looks very beautiful… It is a very beautiful place on my street. I consider it beautiful'* (MX-U3). In addition to the building's beauty, the values attributed by the users to the buildings include architectural value, historical value and originality. The exterior characteristics that are appreciated include the facades, orientation and number of floors, whereas the interior characteristics include the structure, distribution, amount of space, materials, natural ventilation and natural light. Users prioritise the preservation of original facades as a valuable opportunity for future generations. *'Their facades have been preserved impeccably and are as they were many, many years ago. No entries or exits have been modified; they are as they were bought by the family of my children's great-grandmother'* (MX-U3).

4.2. Heritage values assigned to historic buildings

The historical value was the primary value associated with the properties: *'Well, for the year it was made, and for its architecture, balconies, and corridors because it is very beautiful. I like everything. I like it a lot"* (MX-U2). The historical context also reinforces the owner's relationship with the architectural, aesthetic and symbolic value over time. The residents endeavour to maintain the original building as much as possible because of its architectural and sentimental value, in part due to familial ties: *'Well, the greatest meaning is sentimental because I have lived here (for many years), and this is where my father, my uncle and my husband died; I met my husband here, and my son was born here'* (MX-U2). The familial attachment to the property (Figure 2) seems to have a significant relationship when mapped on Vensim; the owner has a reason for living on the property, which is strengthened over time despite the fact that the physical conditions of the apartments (original materials) require maintenance.

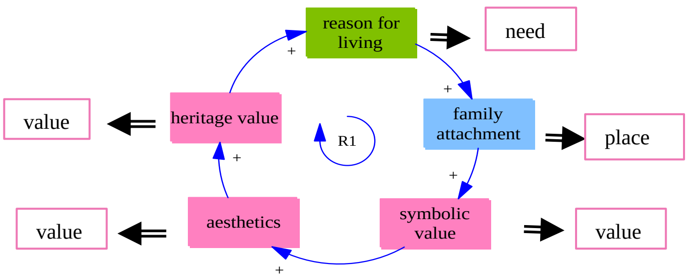

Figure 3. Reinforcing loop of value

4.3. How users think about changes to the condition of the building over time

Excess humidity has deteriorated the materials of the original facades of all buildings, which has increased the cost of interventions and maintenance due to the aesthetic value of the properties. The users were aware of the relationship between humidity, deterioration and use and the need to maintain the original facades and materials in good conditions. MX-U5 said, *'Yes, it is because the use of buildings has changed over time. For example, (original materials) need a lot of maintenance'*. While changes to windows were made because of deterioration and humidity, over time, changes made were further driven by the durability of the new materials. However, despite the cost, deterioration and time, users demonstrated willingness to preserve the original materials and turn to government programs for interventions. *'The roofs need waterproof paint and, on the facade, some painting. The FIDEICOMISO (Historic Centre Trust) approved to carry out the interventions on the façade' (MX-04).* Despite these conditions, residents feel satisfied with the maintenance given and resist making massive changes. Such resistance is also related to the architectural value, the high cost of intervening in heritage buildings and listed status. As indicated by (MX-U2) *'costs are high because all the interventions have to be performed by specialised people'*.

4.4. Negotiating thermal comfort, energy efficiency and heritage conservation

In terms of indoor environmental conditions, thermal comfort is important for the residents. Most residents perceived their building as cold in winter but cool and pleasant during summer. As reported by one resident, *'During the winter, it is a little cold... I always bring my coat. In summer, it is a delight, …to get inside from the street and find natural air conditioning thanks to the height of ceilings and thanks to the walls that maintain a delightful temperature. It is very nice'* (MX-U1). Mexico City, in most of its territory, has a temperate sub-humid climate (87%). The ideal thermal conditions for most residents were between 20 to 30°C. MX-U1 stated that, *'I say 28–30 °C [would be the ideal temperature for me]'*. Most residents perceived their building as being cold in winter but cool and pleasant during summer. As reported by MX-U3, *'Well, right now, it is a little bit cold, but here. When it is very warm, I open the windows, and it gets colder. During the winter, I close them, and it keeps the inside temperature warmer because the roof retains the interior heat, so the climate is stable.'* The residents control the inside temperature by opening and closing the windows or using heating during the night (as a last resort), but users would not like to use it. Because of the buildings' original features and aesthetic value, the residents feel satisfied and resist making changes. However, they would consider making changes (as minimum as possible) using modern materials for windows and doors (because the intervention will last longer) in the case of severe deterioration. Nevertheless, regarding certain materials replaced for floors and ceilings, the users regret some interventions made; *'Well, for the floor, it was cosier with the original material (wood) and it was warmer inside the apartment, so I believe that should not have been removed...."* (MX-U2). Monitoring showed that users' perception of the buildings' relative humidity is different, and they feel discomfort. Monitoring showed that relative humidity and temperature are average (Figure 4).

Figure 4. Monitoring of relative humidity, indoor temperature, mean external temperature and mean external relative humidity

The interior temperature was also perceived differently depending on the number of floors occupied, although there was a consensus that the indoors were cold. Some apartments lacked direct solar radiation during winter due to their orientation and interior layout. For instance, a first floor north-oriented façade was perceived as cold compared to a façade with the same orientation but on the fifth floor, where it was perceived as warm. The natural ventilation and size of rooms improve the users' perception of thermal comfort. The users open windows in the morning daily for a couple of hours. However, they keep them shut when the perceived temperature has dropped. Thermal comfort is also reinforced by time; the more time residents have spent in the property, the more the user is aware of the seasonal changes affecting thermal comfort. Despite the thermal comfort described above for winter, the users were not prepared to make interventions to the buildings for three main reasons: the attachment to the building and its value (due to its sentimental, architectural and historical value), the barrier to interventions given by the listed status of the historic area and a drive for preserving buildings for future generations. In general, if residents felt thermally uncomfortable inside, they would consider making minimal changes for improvements such as changing materials of the floors and ceilings. They also expressed a willingness to make interventions for reducing energy consumption (e.g., solar panels on the roof). However, this has not materialised due to the government's restrictions and the associated costs for listed buildings on a heritage site.

5. Conclusion

Current research on how residents of historic buildings negotiate their need for thermal comfort, reduced energy bills and heritage conservation shows that the values they attribute to the building can be critical in the negotiation process. Values are also changeable. In the case of Mexico City Historic Centre, users resist changes to original features of the building, such as changing windows over time. A pre-set of non-negotiable heritage values is provided by heritage guidelines to which the energy efficiency policies need to adhere. The non-negotiable nature of the heritage values is inevitably more prominent in protected areas. In contrast, the need for energy efficiency changes can be rather high for some residents. This issue becomes even more challenging in the context of social housing which was examined as part of this study. The heritage area was occupied by social housing inhabited by people with limited resources, while other buildings that have been conserved and renovated were privileges for commercial uses. The dynamic relationships explored showed that heritage values, preservation, thermal comfort and energy efficiency are at interplay when residents decide over energy and thermal comfort interventions. The values associated with the building's tangible characteristics and meanings unquestionably affect what elements residents are willing to change or maintain. However, there is a usual diversity of values, and each case is unique. It is due to this uniqueness that a participatory approach to sustainable design and renovation is required that assesses the individual's heritage values and needs (financial, social, energy or thermal comfort related) alongside the individual characteristics of the building instead of applying a universal, standardised approach to the building. Current and future guidelines need to integrate the need for a participatory approach to sustainable design in the context of historic buildings. In the case of Mexico, we showed that the owners and tenants appreciate similar values as heritage professionals such as architectural, historical and aesthetic values. They significantly value the aesthetics of the façade. This may be explained by the fact that the area has been a World Heritage Site since 1987; thus, the residents have had time to adopt the value system. Alongside those values attached to physical attributes of the building, there is a strong familial attachment. By preserving the original materials, residents sustain the sentimental value associated with personal and family memories, and on a practical level, they sustain the building for future generations. This study adds to the knowledge base on this subject by using an example from Latin America, where no studies on this topic have been conducted. Current studies on how users' heritage values drive or prohibit energy efficiency interventions in historic buildings are derived mainly from Europe. Therefore, by examining Mexico, we can gain new insights into the subject matter. The residents used their own means to adapt their needs to the space, temperature and humidity (e.g., wearing more clothes, closing windows and blocking the cold air from outside). These actions passively provide thermal comfort and low-cost solutions. The final objective for energy efficiency in heritage buildings, in any case, must be to balance the different needs of users and values comprehensively and effectively. This work developed methods and a strategy to conserve the built environment's historical and cultural value in Mexico City. The present research will help the decision-making process associated with energy efficiency which includes the importance of heritage. Given the rapid growth of cities leading to greater consumption of resources, a sustainable federal and local legislative framework will need to be continuously updated. Practices and tools for historic centres should put heritage buildings and users in Mexico on a sustainable path to continue mitigating climate change, thus serving as a model for other Latin-American countries.

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