



Local Culture and Urban Retrofit: Reflections on Policy and Preferences for Wall and Roof Materials

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Retrofitting strategies aim to reduce environmental footprints promoting the development or upgrade of existing infrastructure. One crucial aspect of successful retrofitting strategies is local culture, which can harmonise or come into conflict with retrofitting initiatives. However, investigations on the influence of local practises, particularly in the global south, are limited and such influence deserves more attention. This article explores the connexion between local culture and retrofitting strategies, focusing on wall and roof material selection in the Metropolitan Valley of Oaxaca in Mexico (ZMVO). We begin with a brief review of the retrofitting initiatives at related governmental levels. Then, through a survey, we analyse the choices and reasons for selecting specific materials for walls and roofs in the ZMVO. We discuss to what extent cultural practises and preferences have been considered or left behind in the strategies and ensuing challenges. The findings confirm important premises. First, tradition and community support were not relevant factors in wall or roof material selection. Material reuse, energy efficiency, and sustainability-related reasons were also not essential to the preferences. Instead, protection (against rain, earthquakes, theft and accidents), hygiene, and aesthetics had a consistently higher priority. We also found that poverty or lack of other options intersects with the use of precarious materials, creating constrained choices. However, the most crucial finding was that choosing less environmentally or culturally compatible materials was strongly connected with deprivation, having important implications in the selection of materials and retrofitting strategies. The current retrofitting initiatives call for sustainability and efficiency, but the local practises render these efforts insufficient and incoherent. Poverty and informal housing are the main emphases of the local policy. However, the policy focuses on new infrastructure and much less on the existing housing, causing less efficient retrofits. Guidelines for more sustainable material selection have advanced, but regulation and enforcement remain weak. We conclude by discussing all these challenges and providing a set of recommended actions in new initiatives.

Keywords: retrofitting, social inclusion, low-carbon transitions, urban retrofit, local culture, building enclosure, policy, Global South

INTRODUCTION

One key strategy for achieving ambitious carbon and energy reductions is urban retrofitting. Retrofitting refers to the development or upgrade of the existing infrastructure of a city or region to reduce energy consumption (Dixon and Eames, 2013). Retrofitting strategies cover diverse aspects of low-carbon reconfigurations on houses, buildings, and common areas (Dixon, 2014). These focus on resilience, security, and ecology (Eames et al., 2014; Hodson and Marvin, 2017). By upgrading materials and incorporating more efficient technologies, energy and carbon emissions are curtailed (Gupta and Gregg, 2016).

Urban centres have the greatest potential for retrofitting strategies because they have the highest energy consumption rates. Therefore, retrofitting literature has placed considerable interest on it, focusing on new dwellings in urban cores and the periphery of cities (Eames et al., 2013). However, there is less attention on the redevelopment of existing suburbs (Dunham-Jones and Williamson, 2008), and urban retrofitting perspectives from the global south, which are increasing but insufficient compared to higher-income nations (Silver, 2014).

The perspective from rising urban centres in developing countries requires presence because of the potential environmental stress from their growing economies and populations (Cohen, 2006). In most of these contexts, existing infrastructure in the suburbs is also more critical, given the more informal settlements. Some factors can also undermine retrofitting strategies, such as pressures associated with poverty, economic development, land use, and governance (Dixon et al., 2018). Culture could be another type of pressure, given that retrofitting initiatives can come into conflict with socio-cultural elements (Sunikka-Blank and Galvin, 2016; Khalid and Sunikka-Blank, 2017). Nevertheless, many retrofitting initiatives overlook this, and it has surprisingly received little attention in academic literature (Opoku, 2015; Rau et al., 2020).

One crucial perspective for retrofitting literature from the developing world is Latin America (LA). LA has two of the five largest megacities (Mexico City and São Paulo) and large populations living in smaller urban centres (Vargas et al., 2017). Secondary cities¹, in particular, are expected to grow rapidly, but a large percentage of households still have inadequate materials and other deficiencies that retrofitting policy should address. However, the unique peculiarities of local contexts are neglected, and the experience in larger cities are ignored (Gillich et al., 2018). Furthermore, rural traditions in smaller urban settings are usually decisive in local practises. For example, the use of fuelwood for cooking, the mixed provision of space and water heating with cooking, or the use of adobe² and other traditional materials are commonplace. Climate is also varied, resulting in a wide diversity of contexts where policy should be implemented (Tahsildoost and Zomorodian, 2020).

For cities in southern Mexico (Oaxaca, Guerrero, and Chiapas) further challenging conditions exist. Deficient housing

intersects with informal employment (Alvarado Juárez, 2008) and poverty (CONEVAL, 2020) in contexts of indigenous presence. Thus, understanding local practises and preferences in selecting household materials and in the provision of energy services is essential for retrofitting strategies.

A growing literature has demonstrated how the behaviour of inhabitants of residential buildings affects energy use (Stephenson et al., 2010; Gram-Hanssen, 2014). Activities, expectations, aspirations, and social contexts of everyday life can significantly influence energy consumption (Stephenson et al., 2015; Rau et al., 2020), and this knowledge has significant consequences on the success of retrofitting policy (de Feijter et al., 2019; Stephenson et al., 2021). However, the study of such connexions in the global south is not as solid, particularly in mid-sized cities.

Based on the above, this article explores the role of culture and preferences in designing locally-oriented retrofitting strategies. We focus on a middle-sized ethnically diverse metropolitan area with a rising economic activity: the Metropolitan Area of Oaxaca City (ZMVO in Spanish), i.e., the city of Oaxaca de Juárez and 22 surrounding municipalities.

We start with a review of the principal retrofitting policies at different government levels. Then, we analyse preferences that could explain the reasons for using certain materials in walls and roofing in the urban core and suburbs within the ZMVO. For this, we design a questionnaire based on the national energy consumption survey (INEGI, 2018b) with additional items on the preferences for material selection (economic, environmental, safety, aesthetics, hygiene, tradition, and community support among others). Then, we survey households and finalise discussing the results in light of relevant retrofitting literature, centring on the role of the local culture in retrofitting strategies.

METHOD

Methodology

To investigate local culture in retrofitting strategies in the ZMVO, we adopt a two-stage methodology. We first review the retrofitting policy in Mexico at the three levels of government—the federal, the state, and the metropolitan levels—to identify all retrofitting initiatives. Details are provided in section Retrofitting Policy Review Process. We then survey the preferences in selecting wall and roof materials—the design of a questionnaire and the survey are detailed in section Questionnaire for Wall and Roof Material Preferences. We conclude by discussing the findings from both policy and local preferences and the implications for retrofitting policy design.

Retrofitting Policy Review Process

We review retrofitting policies through the core documents related to housing features, materials, and household energy efficiency in Mexico. We include governmental plans, guidelines and regulations related to housing, national standards directing the use of materials, and the most updated governmental policies for construction and retrofitting strategies. This information is summarised at the federal, state and municipal level, emphasising the local initiatives.

¹Officially, UN-Habitat defines a secondary city as an urban area with a population of 100,000 to 500,000 (Bermudez et al., 2019).

²Adobe is a traditional clay material widely used in Mexican temperate regions.

TABLE 1 | Principal reasons hypothesised in the selection of wall and roof materials.

| Factor group | Reasons for selection (factors) |
|------------------------------|--|
| 1 Economic | Low cost |
| 2 Practical | Easy/fast to build |
| 3 Protection | Protection against natural disasters, accidents, animals Protection against theft |
| 4 Hygiene, maintenance | Hygienic or cleaner *Waterproof (only for roofs) |
| 5 Aesthetics | Visually beautiful |
| 6 Tradition, local community | To follow a tradition To support my community |
| 7 Constrained selections | Already there No other option in the community |
| 8 Environment | Reuse of materials Energy efficiency |

Questionnaire for Wall and Roof Material Preferences

We then surveyed the preferences for wall and roof materials in the ZMVO in October and November 2020 using Qualtrics® XM Software, which has a built-in location and time tracking to filter responses outside the target location.

The questionnaire comprised 29 items structured in four main sections:

1. Background information of respondents (sex, ethnicity, education, occupation, etc.).
2. General information about the household (income, location, size, type, rooms, electric and water supply).
3. Wall materials, reasons for the choice, and wish/motivations for change.
4. Roof materials, reasons for the choice, and wish/motivations for change.

The questions in the first and second section, as well as those inquiring about the type of walls and roof materials, were similar to the ones in the National Household Survey (ENIGH) (INEGI, 2018a) and the National Survey on Energy Consumption in Households (ENCEVI) (INEGI, 2018c). Using these official databases simplified the design of these items and helped to corroborate the obtained sample. The types of materials can be classified into five groups for walls: (1) concrete and cement, (2) bricks and stones, (3) adobe and earthy organic materials, (4) wood, and (5) sheets (metal or asbestos); and for roofs: (1) concrete and cement, (2) tiles, (3) thatching, (4) wood, and (5) sheets (metal or asbestos).

The additional questions on the selection of wall and roof materials were the focal content of the analysis. We designed these questions using twelve/thirteen factors hypothesised as principal reasons for selection, classified in eight large groups (Table 1). The first group encompassed economic reasons. The second, perceptions that the material is practical for use or in the construction. Third, concerns on protection against natural

disasters, theft, accidents or wild animals. Fourth, concerns on hygiene and maintenance of the material. Fifth, related to aesthetics and visual beauty. Sixth, involving tradition or local community support. Seventh, related to constrained selections, such as roofs and walls already built with those materials or lack of other choices locally. Finally, eighth, related to energy efficiency, reuse of materials or any other aspect. Respondents were asked to select the five most meaningful and rank them in importance using the “Pick, Group, and Rank” question type in Qualtrics XM (Qualtrics, 2020). For a complete summary of all the questionnaire items, please refer to **Supplementary Table 1**.

To collect the data, we utilised a non-probability sampling frame and verified it with official statistics. Although we initially intended to bring an equal representation of materials in the sample, given the difficulty to obtain data with an increasing rate of COVID-19 infections in the ZMVO during collection, we opted for a chain-referral method. A group of students from the Universidad Tecnológica de los Valles Centrales de Oaxaca (UTVCO) acted as volunteers to recruit respondents through their local contacts. This sampling choice could ultimately represent respondents with similar backgrounds and consequently possible bias. However, the proportions of demographics, household types, and materials were verified after collection to guarantee the reliability of the sample. This procedure consisted of comparing the proportions with the official statistics mentioned above.

RESULTS

A Brief Review of Retrofitting Strategies in Mexico

Having reviewed the main retrofitting initiatives in Mexico, it is noticeable that institutional interest in housing has a long history. However, the strategies feature a few concerns on local culture and the environment. The concept of sustainable housing has only appeared recently in policy, but more specific and localised guidelines are still needed, as well as further considerations about local culture. This brief review will provide the basis for these findings.

Retrofitting in Federal Government Policy

The first mention of housing in Mexican laws appeared in the national constitution of 1917, in which housing was declared a mandatory benefit (Villar Calvo, 2007). However, it was not until the 1970's that it materialised institutionally with the creation of the Institute of the National Housing Fund for Workers (INFONAVIT) and the Housing Fund of the Institute of Social Security and Services for State Workers (FOVISSSTE). Today, both entities are the principal governmental institutions responsible for developing public housing (CESOP, 2006), supervising the construction by public and private companies.

Environmental and cultural reforms, on the other hand, have appeared only recently. The first amendment to the National Housing Law in 2006 made it mandatory to promote the utilisation of housing materials abiding by national standards (CESOP, 2006), including those adequate for maintaining cultural identity to retain local singularities and diversity (Article

TABLE 2 | Maximum thermal transmittance (U-values) in Mexico (CONAVI, 2017).

| Element | U value [W/m ² K] |
|---|------------------------------|
| Roofs | 0.2725 |
| Walls | 0.3633 |
| Walls in “very dry,” “dry,” and “semi-dry” climates | 0.70 |

TABLE 3 | Maximum thermal transmittance (U-values) in selected countries (EURIMA, 2018; Ahlers et al., 2019).

| Country | U-Value walls [W/m ² K] | U-Value roofs [W/m ² K] |
|-----------|------------------------------------|------------------------------------|
| Mexico | 0.3633–0.7 | 0.2725 |
| Sweden | 0.18 | 0.13 |
| UK | 0.25–0.35 | 0.13–0.20 |
| Germany | 0.3 | 0.2 |
| Austria | 0.35–0.5 | 0.2–0.25 |
| France | 0.36–0.4 | 0.2–0.25 |
| Italy | 0.46–0.64 | 0.43–0.6 |
| Spain | 0.66–0.82 | 0.38–0.45 |
| Belgium | 0.6 | 0.4 |
| Portugal | 0.5–0.7 | 0.4–0.5 |
| Greece | 0.7 | 0.5 |
| Macedonia | 0.9 | 0.6–0.65 |

6 part VII). In June 2017, a subsequent reform explicitly emphasised “material quality” and introduced the idea of “sustainable housing” (ONNCEE, 2017). However, the concept of sustainability was not accompanied by a specific definition or notion related to in-use materials or energy efficiency. In a general sense, these reforms have incorporated cultural and environmental concerns, but more specific guidelines were needed to define strategies in different contexts.

In 2017, the federal government, together with the IFC (International Finance Corporation), developed the National Edification Code (CEV for its Spanish acronym) (CONAVI, 2017), established as the primary guideline for housing projects. CEV is the latest attempt to bring together domestic normative and locally adapted international standards for construction and retrofitting. The latest edition states that the selection of the housing construction’s materials should be in accordance with bioclimatic zones—a significant step forward due to its recognition of the climatic diversity affecting household materials (Herrera, 2018). According to the CEV, the ZMVO has a template sub-humid climate (CONAVI, 2017), and the values for optimal thermal comfort and recommended electricity savings must comply with the maximum thermal transmittance factors (U values) in **Table 2** (CONAVI, 2017). As shown in **Table 3**, these requirements are similar to international standards (Atanasiu et al., 2014). However, the code is not compulsory, and the actual thermal transmittance of diverse materials in local households has an extreme variation (**Table 4**).

Other joint programs related to retrofitting strategies between the federal government and foreign institutions exist. The EcoCasa program has promoted sustainable housing

TABLE 4 | Thermal transmittance of diverse materials in Mexican households.

| Material | U-value [W/m ² K] | Reference |
|-----------------|------------------------------|---------------------------------|
| Concrete/cement | 0.53 | Guillén Guillén and Vélez, 2020 |
| Red Brick | 0.814 | Guillén Guillén and Vélez, 2020 |
| Adobe | 0.46 – 0.81 | Moscoco-Cordero, 2016 |
| Wood | 0.13 | Guillén Guillén and Vélez, 2020 |
| Thatching | 0.137 | Guillén Guillén et al., 2018 |

construction through a series of guidelines since 2010 (Infante et al., 2018). The Green Mortgage has incorporated clean technologies in low-income houses since 2011 (Infante et al., 2018). Moreover, the National Appropriate Mitigation Actions (NAMA) set greenhouse gas mitigation guidelines for existing housing in 2013 (Muñoz Torres, 2016).

Despite all these efforts, substantial challenges persist. The Mexican housing sector accounts for 32% of Mexico’s GHG emissions, 16.2% of the total energy and 26% of the total electricity consumption. The government estimates that 33% of the units would require partial to total retrofitting by 2030 (SEDATU, 2014). Meanwhile, the enforcement of the housing laws is difficult, particularly among new and existing private housing for which retrofits usually occur without even knowing the norms. Overall, retrofitting laws and norms seem very well-structured at a document level, but the application of regulations is problematic.

Retrofitting Strategies at the State Level (Oaxaca)

State-level governments adopt the federal housing initiatives, but the marginalised socio-economic conditions might explain an insufficient regulatory control. Furthermore, the state-level review here demonstrates that few policies are created following the local context.

Oaxaca is one example of a culturally diverse state with contrasting conditions. Divided into 570 municipalities, Oaxaca is the entity with the largest number in Mexico. Around 34% of the population can speak an indigenous language, and roughly half of its population lives in cities (INEGI, 2021). However, 94.2% of the municipalities (537) concentrate more than 50% of the population living below the poverty line (Miguel-Velasco et al., 2017), and only 33.2% of the houses have access to basic services, namely electricity, water and sewage (Miguel-Velasco et al., 2017).

The state government sets the housing objectives and strategies in the Strategic Housing and Basic Services Plan (Oaxaca, 2016), which adopts federal housing strategies. It states that “the promotion of new housing or improvements should guarantee access to legal, decent and quality housing with infrastructure and basic services, particularly for regions lagging behind.” More specific strategies mandate that housing improvement and new housing incorporate “adequate and safe” materials. Nevertheless, precise guidelines about the type of

materials are not available. Moreover, the guiding principle of the plan seems to concentrate on reducing the large percentage of housing shortages (Oaxaca, 2016). For example, there are specific targets to reduce 1.9% of “poor” housing at the state level, and retrofitting targets are between 0.5 and 1%. Other strategies are inexistent, especially related to the cultural diversity in the state.

Concerning the regulation, there is a Housing Law in Oaxaca from 2009, but it makes no remarks about materials or sustainable housing (Oaxaca, 2009). In principle, the CEV is the guiding document for household expansion, and potentially, local retrofitting policy.

On the other hand, migration in Oaxaca plays a critical if indirect role in retrofitting practises. Migrants send remittances to relatives for house maintenance and acquisition. From the 570 municipalities in Oaxaca State, 92.8% reported having people working abroad (United States of America) sending money to their families (Cervantes, 2018). It is plausible that these funds are greater than the local budget of initiatives. As a result, government strategies do not have the same reach as the help from migrant relatives to lower-income households.

As noted above, state-level strategies adopt the cultural and environmental concerns found at federal level, but the ethnic and climatic diversity calls for differentiating policies at this level. However, specific policies customised to the varied contexts within Oaxaca are not available.

Retrofitting Strategies in the ZMVO

At a more local level, state laws and regulations are followed, but local strategies related to retrofitting in the ZMVO could not be found.

The ZMVO is composed of 23 municipalities once separated and now merged (see **Table 5**). In the latest census (2015), the total population was 676,400, having grown 4-fold from 1980 to 2015. Land use in the ZMVO has also dramatically increased 15 times (from 836 to 13,000 Ha) during the same years (SEDATU, 2014). This rapid expansion has drastically raised land and housing prices to the extent that it is now the second-highest in Mexico (Miguel-Velasco et al., 2017). Consequently, large informal settlements exist in the outskirts, which are lower-value areas. Given this, housing plans in the ZMVO focus on land use planning and urbanisation over other concerns, including local culture or the environment. For that purpose, the above-mentioned “Strategic Housing and Basic Services Plan” (Oaxaca, 2016) is adopted as the master plan. ZMVO municipalities also have to follow the State Housing Law and the CEV (Mexico, 2006). Meanwhile, one study estimates that housing and retrofitting activities produce 320,000 tonnes of CO₂ per year in the ZMVO (Miguel-Velasco et al., 2017), suggesting substantial environmental impacts.

On the other hand, a unique vernacular architecture was once characteristic of the ZMVO (Torres Zárate, 1999). According to the International Council on Monuments and Sites, it was “the traditional and natural housing way in which communities continuously adapt to social and environmental constraints” (ICOMOS, 1999). This traditional architecture used stone foundations with adobe walls; during colonial times, it also incorporated other materials such as tile roofing and wood

TABLE 5 | ZMVO composition and population in 2015 (INEGI, 2016).

| Municipality | Population |
|-----------------------------|------------|
| 1 Ánimas Trujano | 3,917 |
| 2 Cuilápam de Guerrero | 21,597 |
| 3 Oaxaca de Juárez | 264,251 |
| 4 San Agustín de las Juntas | 9,342 |
| 5 San Agustín Yatareni | 4,334 |
| 6 San Andrés Huayápam | 5,336 |
| 7 San Antonio de la Cal | 23,038 |
| 8 San Bartolo Coyotepec | 9,105 |
| 9 San Jacinto Amilpas | 15,720 |
| 10 San Lorenzo Cacaotepec | 15,735 |
| 11 San Pablo Etla | 15,993 |
| 12 San Pedro Ixtlahuaca | 8,561 |
| 13 San Raymundo Jalpan | 3,336 |
| 14 San Sebastián Tutla | 18,195 |
| 15 Santa Cruz Amilpas | 12,814 |
| 16 Santa Cruz Xoxocotlán | 93,188 |
| 17 Santa Lucía del Camino | 49,459 |
| 18 Santa María Atzompa | 34,115 |
| 19 Santa María Coyotepec | 2,971 |
| 20 Santa María del Tule | 8,918 |
| 21 Santo Domingo Tomaltepec | 2,988 |
| 22 Tlaxiactac de Cabrera | 10,208 |
| 23 Villa de Zaachila | 43,279 |
| Total | 676,400 |

to improve resistance. During the latter half of the twentieth century, and particularly in the last decades, scarcity of local materials, e.g., wood and adobe, and the incorporation of more commercial ones, namely concrete blocks, have influenced the gradual loss of these traditions. Moreover, the considerable rate of migration in Oaxaca also influences the selection of materials for housing. It is common for migrants to provide the funds to retrofit houses and suggest using some materials that are not easy to find locally. Such modifications have created hybrid constructions with reduced climatic compatibility (Zafra Pinacho, 2009).

In sum, the strategies summarised above demonstrate that few concerns have been raised about local culture or the environment at a more local level. More specific and localised guidelines are also needed. **Table 6** summarises the main strategies at different government levels.

Cultural Preferences for Housing Materials in the ZMVO

Having outlined the main retrofitting strategies applicable to the ZMVO, the evaluation of preferences in selecting walls and roof materials demonstrated that tradition, community support, and even environmental concerns are not among the main reasons for selecting wall and roof materials in the ZMVO. Instead,

TABLE 6 | Summary of retrofitting strategies in Mexico.

| Normative/Policy | Latest revision | Application/type | General description |
|---|-----------------|-------------------------------------|--|
| Ley de Vivienda National Housing Law | 2019 | Federal level/mandatory | Establishes and regulates national housing policies, instruments and programs related to housing development |
| CEV National Edification Code | 2017 | Federal to municipal level/optional | Provides the guidelines for designing safe, efficient and sustainable housing in the urban context, considering all existing normative (NMX and NOM) |
| NMX-AA-164-SCFI-2013 Sustainable buildings—criteria and minimal environmental requirements | 2013 | Federal to municipal level/optional | Establishes the environmental criteria and requirements in order to promote the mitigation of environmental impacts |
| NOM-020-ENER-2011 Energy efficiency in buildings: housing building enclosure | 2011 | Federal to municipal level/optional | Establishes the limits of heat gain in the building envelope to ration energy consumption in cooling systems |
| NOM-018-ENER-2011 Thermal insulators for buildings: characteristics and testing methods | 2011 | Federal to municipal level/optional | Establishes the characteristics and testing methods that materials must comply with for utilisation on roofs and walls for buildings |
| NMX-U-125-SCFI-2016 Building-Construction Industry. Roofing Coverings for High Solar Reflectance Specifications and Test Methods | 2016 | Federal to municipal level/optional | Establishes the characteristics and testing methods that materials must comply with to have “High Reflectance Solar Roof Covering” |
| Ley de Vivienda para el Estado de Oaxaca Oaxaca State Housing Law | 2009 | State level/mandatory | Establishes the mechanisms for urban and rural social housing development. Regulates private and public housing construction. |
| Ley de Desarrollo Urbano para el Estado de Oaxaca Oaxaca State Urban Development Law | 2013 | Federal and Municipal/mandatory | Regulates land and population settlements at state and municipal levels |

protection and constrained choices due to poverty or lack of options had a more prominent place in the local preferences.

The survey conducted in the ZMVO gathered a total sample of 451 questionnaires with 77.3% valid samples (365). Responses from Oaxaca City were the largest share (25%) followed by Villa de Zaachila (14%), Santa Cruz Xoxocotlán (8%), and Santa Lucía del Camino (7%). The least represented municipalities were San Andrés Huayápam, San Agustín Yatarieni, and Animas Trujano (all below 1%).

The sample was primarily composed of young adults (mean age 30) with low to mid-income levels and mid to high levels of education. The proportions between males (43%) and females (57%) were balanced, and most respondents had a high school education or above (85%). More than half (66%) were working professionals. Half of the reported incomes were between 85 and 367 USD per month (1,667 to 6,666 pesos), corresponding to a typical lower to mid-income level in the ZMVO. Finally, 46% identified as ethnically indigenous and 35% as mixed-race.

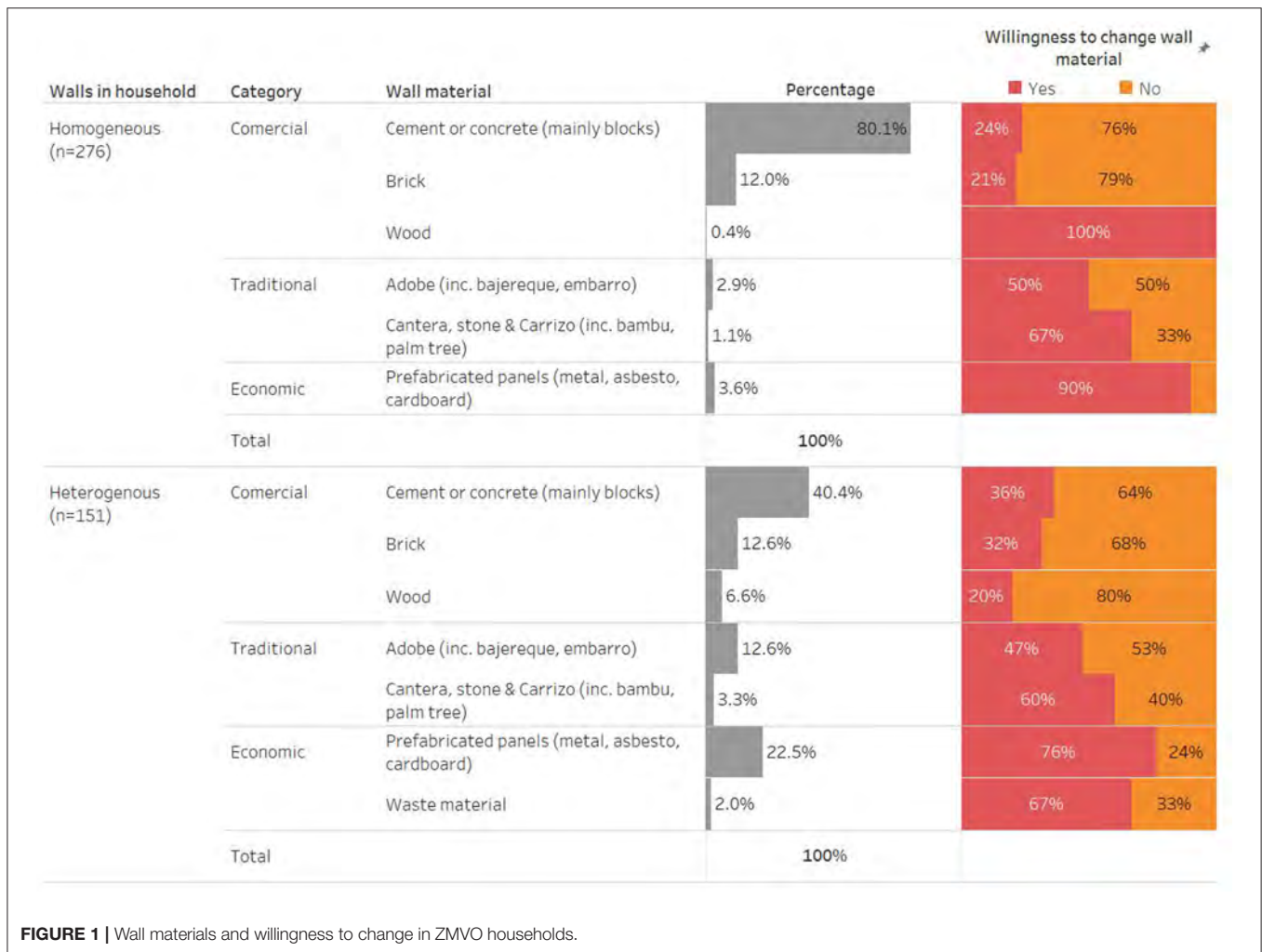
The sample also reflected typical households in the ZMVO. For the most part, respondents lived in individual houses (85%). Only a few reported living in an apartment (6%). Most had access to electricity (98%) and a piped water supply (65%), and some used firewood for heating or cooking (23%). Lastly, 20% ran a commercial business inside the house. **Supplementary Tables 2, 3** summarise all the information above.

In terms of wall and roof materials, the proportions were also typical of the ZMVO. First of all, roughly 80% of households had homogeneous materials in the walls, and it was similar for roofs (84%). The shares were equal in Oaxaca City and the suburbs. Houses with homogenous walls and roofs mostly used

concrete, cement, or brick. However, houses with heterogeneous walls and roofs reported higher use of other materials, such as metal/asbestos panels or adobe.

The results on roof and wall materials indicate a low presence of traditional materials and the use of multiple materials for walls or the roof in the house associated with a more vulnerable condition. For houses with a homogeneous wall, the most represented material was concrete/cement (80.1%), followed by red brick (12%), prefabricated panels (metal, asbestos, cardboard) (3.6%), and adobe (2.9%). For houses with diverse walls, there was an increase of in the share of prefabricated panels (22.5%), adobe (12.6%), brick (12.6%), wood (6.6%), and the proportion of concrete/cement reduced to 40.4% (**Figure 1**). In turn, the predominant material for houses with a homogeneous roof was concrete/cement (80.9%), followed by prefabricated panels (metal, asbestos) (15.6%), and tiles (3.2%). Houses with diverse materials in roofs also reported a higher percentage of prefabricated panels (44.2%), tiles (9.7%), and wood (5.3%), and less use of concrete/cement (40.7%) (**Figure 2**).

The willingness to change to another type of material was notably higher among households with the least favourable types. **Figure 1** demonstrate how fewer respondents with cement/concrete and brick materials in walls wanted a change (21–36%), compared to those using adobe (47–50%), or metal/asbestos panels (76–90%). As for roof materials, there was a similar tendency. Those using traditional and, in particular, economic roof options reported higher willingness to change (**Figure 2**). Among those wishing for a change, people living in houses with homogenous cement/concrete walls chose wood and Cantera stone in the first place (28 and 23%), associating



it with more beauty (Table 7). Those using brick desired cement/concrete (43%) because of increased protection and, surprisingly, more beauty. As for those using adobe, the better choice was brick (75%) due to the increased hygiene. Finally, the ones using metal or asbestos panels wished for cement/concrete (89%), again for increased protection and beauty. The choices for people with multiple walls in the house were equivalent to those for homogenous walls, as well as the preferences for roof materials (Table 8). Households having prefabricated panels and wood predominantly desired cement/concrete (68% and 72% for homogenous and heterogeneous roofs, respectively), and the percentage of households desiring tiles or wood were higher among households using cement roofs (39 and 13% for homogenous roofs, respectively).

The analysis of the reasons behind the selection of materials demonstrates that local traditions and the environment are not essential concerns. Instead, protection, aesthetics, and other aspects, including constrained preferences, had higher importance. We observed a strong correlation between concrete/cement and both protection (against earthquakes and theft) and hygiene. Bricks had a strong correlation with protection, but also with other factors: ease of use, beauty,

and preservation of traditions. Adobe, a fundamentally more traditional material, correlated with ease of use, beauty, and lower cost. Finally, metal/asbestos panels were entirely associated with lower costs, ease of building and the lack of other options (Figure 3).

For roofs, the results were similar. Cement/concrete was associated with waterproofing, protection (theft and earthquakes), and hygiene. Wood was associated with beauty in homogenous roofs, and in heterogeneous roofs, it was associated with a lack of options, low cost, and ease of building. Tiles were associated with beauty, ease of building, and low cost. Lastly, metal or asbestos panels were associated with low cost, ease of building, and lack of options (Figure 4). For both walls and roofs, the option “already there” appeared among the five most selected choices for all materials, supporting the idea that constrained selection was another primary reason for the preference.

In sum, we confirmed that tradition, community support, and material reuse and concerns related to the environment represent a less important reason for selecting wall and roof materials. Households with concrete walls that owners wished to change to wood or Cantera stone were the closest to energy



FIGURE 2 | Roof materials and willingness to change in ZMVO households.

efficiency concerns, as the second most crucial reported reason for the change was to “reuse another material.” On the other hand, the closest group with concerns about local culture were householders with brick walls. The preference for adobe walls or tile roofs reflected more concerns regarding aesthetics. Overall, the most critical concern in material selection was protection against disasters (earthquakes, storms, accidents) or theft, particularly for households in a more vulnerable situation. Our results also indicate that material selection is constrained by economic status. These facts have crucial implications in the design of retrofitting strategies to increase energy efficiency in the ZMVO. In the following section, we will further discuss this perspective.

DISCUSSION

This section discusses the main findings and their implications in retrofitting policy. First, the effect of local culture on urban

retrofit in the context of the ZMVO is examined, followed by recommended actions and concluding with limitations identified in the current analysis.

Local Culture and Implications on Retrofitting Strategies

The ZMVO is an excellent example of the several challenges for retrofitting policy to incorporate the local culture in the global south. From the policy perspective, we noted that the enforcement and compliance with available normative are insufficient, and localised strategies are non-existent. Sustainable initiatives, such as rules on the local origin of materials, have been recently incorporated in the main construction guidelines. However, these have not sufficiently materialised in more operational programs. Moreover, in general, existing households receive less attention, despite their more prominent role and potential impact in retrofitting initiatives.

TABLE 7 | Wall materials and ideal types in ZMVO households.

| Category | Wall material | Walls in household | Desired material | Percentage | |
|----------------|--|--|------------------|------------|-----|
| Comercial | Cement or concrete (mainly blocks) | Homogeneous | Wood | 28% | |
| | | | Cantera, stone | 23% | |
| | | | Brick | 17% | |
| | | | Adobe | 15% | |
| | | | Others | 17% | |
| | | Heterogenous | Cantera, stone | 18% | |
| | | | Wood | 18% | |
| | | | Adobe | 14% | |
| | | | Brick | 14% | |
| | | | Others | 36% | |
| | Brick | Homogeneous | Cement | 43% | |
| | | | Cantera, stone | 14% | |
| | | | Wood | 14% | |
| | | | Others | 29% | |
| Heterogenous | | Adobe | 33% | | |
| | | Cantera, stone | 17% | | |
| | | Others | 50% | | |
| | | Wood | 100% | | |
| Traditional | Adobe (inc. bajereque, embarro) | Homogeneous | Brick | 75% | |
| | | | Cement | 25% | |
| | | Heterogenous | Brick | 44% | |
| | | | Cement | 33% | |
| | | | Cantera, stone | 11% | |
| | | | Others | 11% | |
| | Cantera, stone & Carrizo (inc. bambu, palm tree) | Homogeneous | Wood | 50% | |
| | | | Others | 50% | |
| | | Heterogenous | Cement | 67% | |
| | | | Brick | 33% | |
| | Economic | Prefabricated panels (metal, asbesto, cardboard) | Homogeneous | Cement | 89% |
| | | | | Wood | 11% |
| | | | Heterogenous | Brick | 58% |
| | | | | Cement | 8% |
| Adobe | | | | 4% | |
| Cantera, stone | | | | 4% | |
| Wood | | | | 4% | |
| Others | | | | 23% | |
| Waste material | | Heterogenous | Wood | 100% | |

Private owners place more concern on protection than on the environment, tradition, or local identity when retrofitting occurs. The vast majority of those who currently lack resistant materials in roofs and walls desire, and require, protective options. The natural choice is to upgrade to concrete blocks. However, concrete incorporated in traditional houses diminishes thermal comfort (Torres Zárate, 1999), gradually requiring extra heating or cooling equipment. We confirmed the differences with the thermal transmittance values in Mexican households (Table 4), and some householders already using these materials considered adobe walls and tile roofs more thermic and aesthetic.

Nevertheless, adobe, brick, or tiles are socially associated with poverty, primitive housing, and rural regions (Contreras and Contreras, 2017). In contrast, concrete blocks suggest a higher status (Torres Zárate, 2005), particularly among households with inadequate wall and roof types. Furthermore, the use of inadequate materials can intersect with other vulnerable conditions, such as deficiencies in water supply or sewage, unstable sources of income, and poverty, exacerbating the vulnerability. This fact has been demonstrated in recent studies on energy poverty (Ochoa and Graizbord Ed, 2016; Ochoa et al., 2020) and limited access to energy services (Cravioto et al., 2014; Ochoa et al., 2021). Thus, the desire for less

TABLE 8 | Roof materials and ideal types in ZMVO households.

| Category | Roof material | Roofs in household | Desired material | Percentage |
|-------------|--|--------------------|------------------|------------|
| Comercial | Cement or concrete | Homogeneous | Tiles | 39% |
| | | | Wood | 13% |
| | | | Others | 48% |
| | Wood | Heterogenous | Cantera | 67% |
| | | | Wood | 33% |
| | | | Cement | 100% |
| Traditional | Tiles | Homogeneous | Cement | 50% |
| | | | Panels | 50% |
| | | | Cement | 67% |
| | Prefabricated sheets (metal, asbestos) | Heterogenous | Wood | 33% |
| | | | Cement | 72% |
| | | | Tiles | 13% |
| Economic | Prefabricated sheets (metal, asbestos) | Homogeneous | Cement | 68% |
| | | | Tiles | 20% |
| | | | Wood | 3% |
| | | | Others | 10% |
| | Wood | Heterogenous | Cement | 72% |
| | | | Tiles | 13% |
| | | | Wood | 6% |
| | | | Others | 9% |

environmentally or culturally compatible materials strongly connected with deprivation is one of the most crucial aspects of retrofitting policy.

Besides this, the ZMVO also reflected other unique characteristics worth discussing. For example, apartments are scarce, and houses are the norm. Almost half of the households identify themselves in existing indigenous groups (Zapoteco, Mixteco, and others). Houses have a traditional nature of more open space, and 25% have firewood kitchens, which often also provide thermal comfort in winter. Cooling and heating of spaces are required only on a limited number of days, so almost no households use air conditioning or heaters. Thus, retrofitting strategies should target this local energy culture, distinct to typical urban settings in the global north, denser and mainly relying on gas and electricity to provide energy services (Silver, 2014; Gillich et al., 2018; nZEB-RETROFIT, 2021).

Finally, not all households are in similar conditions to receive benefits from state programmes. Silver (2014) suggests that housing initiatives cannot support many low-income households because they usually do not have title deeds required to obtain retrofit credits. This could explain why remittances are essential contributions to improve housing among lower-income households (Cervantes, 2018). In these cases, it is not rare that

retrofits use materials similar to those used where migrants live, which turn out to be less effective for the local climate, again affecting environmental performance. The incorporation of all social groups is a crucial matter.

In sum, the priorities for urban retrofit in the ZMVO are distinct from other dense urban contexts in Mexico and most of the global north, where efficient technologies to reduce electricity consumption for heating and cooling spaces are the main targets of action (Goggins et al., 2016).

Recommended Actions

On the one hand, adopting more general master plans might not be easily adjustable to local retrofitting activities. Thus, we detect that governments need to create more specific guidelines tailored to the region, where locally compatible energy-efficient retrofits are easier to identify. There should be strategies to retrofit walls and roofs with a culturally and environmentally sound vision, currently unavailable. Considering the existing norms, manuals, guidelines, and construction codes at different government levels, it is clear that the enforcement of regulations is still challenging for housing development within the ZMVO. However, the adoption of master plans alone will not be easily adjustable to the actual retrofitting activities in the ZMVO.

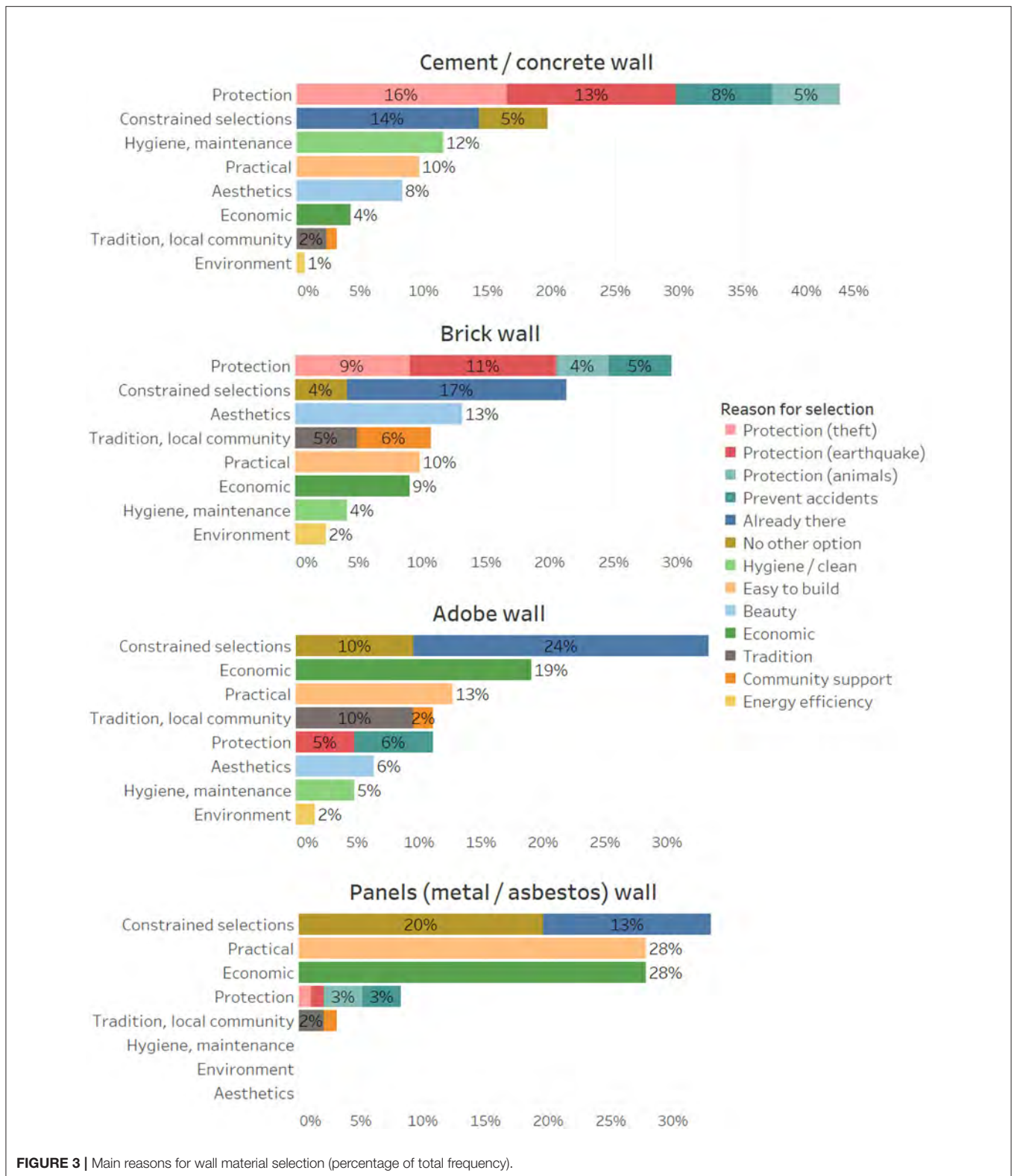


FIGURE 3 | Main reasons for wall material selection (percentage of total frequency).

The local design of retrofitting strategies will face social challenges glimpsed through the analysis presented. The most crucial aspect is probably the connexion between deprivation and

the less efficient use of resources. This needs a more inclusive perspective. Around 20% of houses had inadequate materials. A large percentage may also intersect with other vulnerable

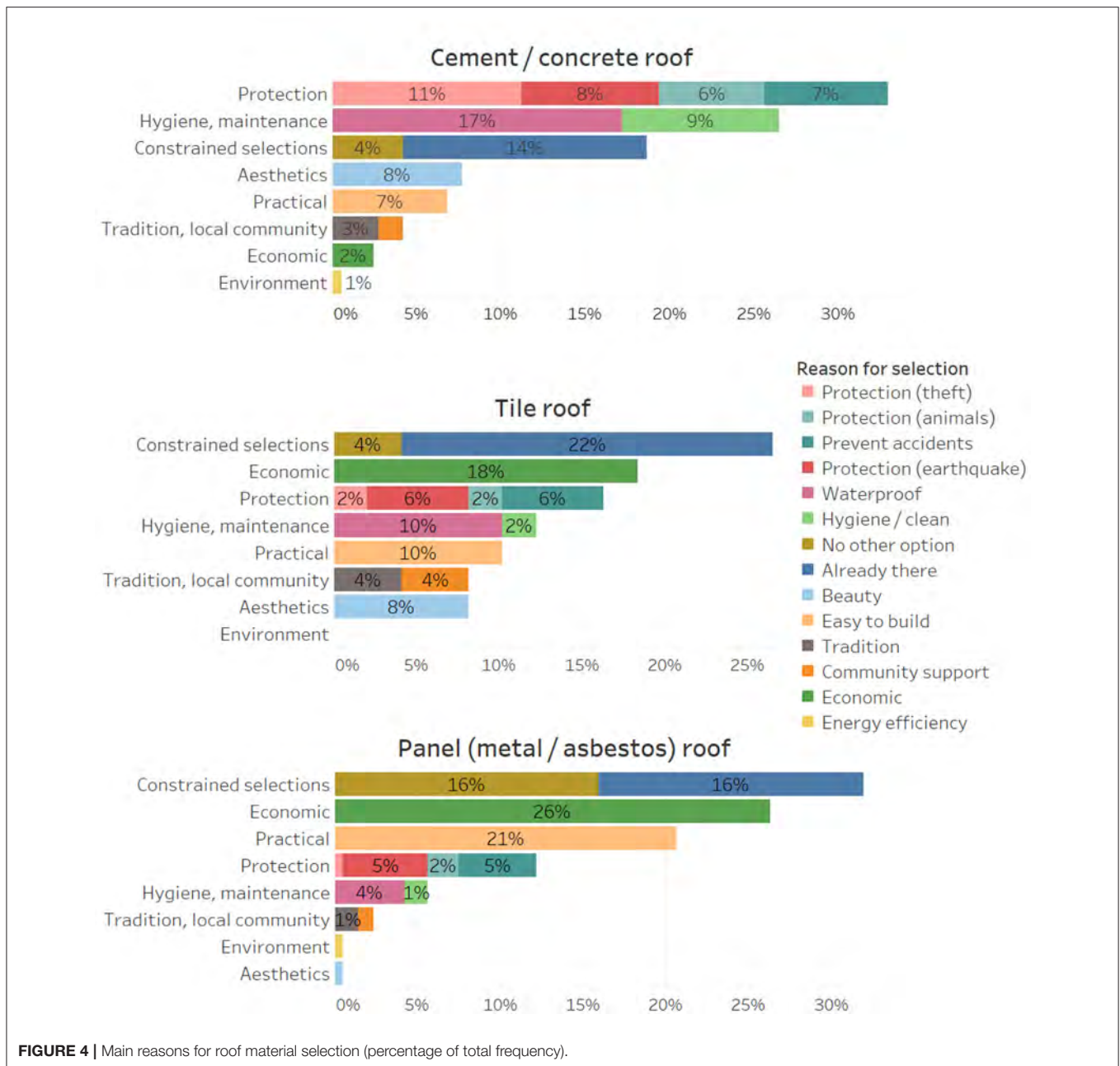


FIGURE 4 | Main reasons for roof material selection (percentage of total frequency).

conditions, such as deficiencies in water supply or sewage, unstable sources of income, and poverty. For these groups, it is essential to facilitate retrofits that reduce vulnerability while understanding local practises in the provision of energy services. Strategies should target simple but effective low-cost retrofits.

Wall and roof materials seem to have crucial roles in more efficient energy use for thermal comfort. The advantages and disadvantages of modern and traditional materials need to be incorporated in policy for new or existing infrastructure. There are already materials on the market that help the passive use of energy for thermal comfort. An example is waterproofing on roofs that can reflect heat, keeping the rooms cooler in

summer, and allowing better thermal insulation in winter. This is just one example of a simple strategy that, despite being relatively accessible, has not been considered enough. In this sense, there is a substantial opportunity for policy to identify and promote traditional practises that develop highly efficient and protective materials at lower costs. Also, it is essential to identify newer versions of traditional materials, which could overcome recognised weaknesses.

Additionally, financial mechanisms for retrofits should be more accessible and explicitly target sustainable housing. On the one hand, social housing credits should be obtained based on the degree of sustainable and energy materials used on the

projects. More transparent mechanisms of incentives for housing constructors and individuals are also needed. On the other hand, credits should be available for informal and independent workers. Considering the limitations in the ZMVO, new governmental institutes established exclusively for sustainable building concerns seem difficult. However, we advocate for simple but effective programs inside the local agencies in charge of urban development programs.

Not only the government, but other agents involved, can contribute to retrofitting strategies. Independent institutes such as the Cadaster Institute (ICEO is its Spanish acronym), currently in charge of assessing technical consultancy and valuation of local properties (Lucero-Álvarez et al., 2016), could be one example. This institution or others with similar faculties could assess and validate the proper utilisation of energy-efficient materials for the ZMVO housing. They could issue a certificate that can reduce, for example, the yearly housing tax.

These recommendations should be reviewed in detail in future studies, and are fertile areas to discuss new policies for the utilisation of energy-efficient materials in the ZMVO.

Future Visions in Retrofitting Policy

It is conceivable that economic conditions in the ZMVO may improve given the numerous economic stimuli in the region. According to the National Development Plan (PND) 2019–2024 (Government, 2019), the budget to support and encourage investment in the southeast part of the country amounts to 41.3 billion pesos (SCT, 2018), the highest percentage of the current federal administration. If this is successful, modern rail infrastructure and greater economic diversification from 139 strategic works will materialise (Rosales, 2019), among them highways and rural roads, the commercial port of Salina Cruz, and the trade corridor of the Isthmus of Tehuantepec.

This development will significantly impact the creation of housing in larger cities and the retrofits to existing houses. The selection of materials will affect the outcomes and equipment for heating, cooling, and hot water supply. In other words, the energy demand could increase in the ZMVO and other similar cities in the southeast. Thus, locally oriented retrofitting strategies will be essential.

In the global north, retrofitting literature is focusing on how new technology in buildings can create Positive Energy Blocks (ZEB) and Districts (PED) (Bisello, 2020; Verhaeghe et al., 2020; Lindholm et al., 2021). However, these notions are very distant from the needs in the ZMVO and probably other similar mid-size cities in developing countries. Authorities can direct the creation of infrastructure for easier transitions into efficient housing, using modern solar and hybrid power technologies. However, socio-economic conditions, the nature of local buildings and practises, and the marginal installed capacity of domestic solar technologies suggest a different strategy in these contexts. Many cities in Mexico have a great potential for more extensive use of solar technologies in homes (Grande et al., 2015) because climate conditions are favourable (Pérez-Denicia et al., 2017), and the regulation for domestic generation is prepared (Grande et al., 2015). However, the high percentage of homes in economic

vulnerability and the local practises discussed above remind us of other realities to consider.

Limitations

This study utilised a questionnaire to shed light on the residents' perspectives in the ZMVO. However, there are inherent limitations in using this method to extract conclusive remarks on the local culture when selecting roof and wall materials. First, the use of questionnaires to evaluate experiences can evoke judgements articulated on heuristic answers, meaning that respondents may substitute the reason for selecting the wall and roof materials with a quicker, easier, and more accessible answer, as noted in behavioural sciences (Kahneman, 2011). We have carefully followed recommended guidelines in designing our survey structure and questions (Robinson and Leonard, 2018) to avoid usual cognitive problems on the questions regarding the householders' experience. However, we acknowledge that perfectly reasoned answers are challenging to obtain, given the ordinary tendency to substitute these questions.

This limitation suggests the necessity for complementing the observed preferences with ethnographic methods or other qualitative modes of inquiry, which could possibly validate the observed preferences and compliment the information on the reasons for the selection stated among householders who have recently engaged in retrofitting activities. Another helpful technique could be direct participant observation, which could assist in extracting more symbolic notions behind the answers (Shove, 2003). The current limitations accessing the ZMVO due to the COVID-19 pandemic makes it difficult to conduct these methods, but is another fertile ground for further research.

In addition, a large part of the literature suggests that retrofitting encompasses other stakeholders, such as developers and financiers (Dixon and Eames, 2013; Dixon et al., 2018). Although currently out of the scope of this article, targeting these would complement the current findings. The role of private agents and construction companies is equally important in the design of retrofitting policies.

Finally, further research should also address local preferences connected with other retrofitting aspects not considered in this article. Among these, we have sanitation, solid waste, public spaces, and workplaces. The concept of retrofitting encompasses a broader notion, including measures creating substantive change in city infrastructure (Eames et al., 2014; Hodson and Marvin, 2017).

CONCLUSION

This article analysed cultural preferences in selecting wall and roof materials in the Metropolitan Valley of Oaxaca and the implications in Mexican retrofitting strategies. We found that retrofitting in Mexico has advanced substantially in recent years through a review of related norms, guidelines, and policies. However, the application and enforcement of retrofitting strategies have also faced challenges.

Overall, retrofitting policy focuses primarily on poverty. At the state level, the primary objective remains on resolving informal housing and inadequate materials. Culturally compatible and

environmentally friendly housing is not visible in local initiatives. Energy efficiency, passive design, efficient equipment, and local materials for more sustainable building need to be tailored to local needs.

Local governments in the ZMVO are active in implementing programs following federal or state-level directives, but retrofitting policy at that level is limited. Consequently, retrofitting strategies do not consider climate variations, the priority of specific energy services, or transformations in the use of equipment. In addition, the emphasis of policy is entirely on new infrastructure. For existing infrastructure, the programs and guidelines are marginal.

It should be noted again that houses in the ZMVO have a traditional nature of more open space as well as firewood kitchens that are used for cooking and often also for providing thermal comfort. Therefore, effective retrofits should consider these practises, different to other urban settings. Wall and roof materials have relevant roles in the retrofits compatible with these local preferences. The advantages and disadvantages of modern and traditional materials for new or existing infrastructure need a place in future policy.

From the householders' perspective, we found, the selection of materials for roofs and walls do not relate to energy efficiency or concerns about traditions and local culture. Instead, importance is placed on protection against environmental disasters or crime, particularly among households with precarious materials. The natural choice, therefore, is to upgrade to concrete blocks. However, concrete incorporated in traditional houses diminishes thermal comfort, and adobe walls and tile roofs represented a more thermic and aesthetic option for some householders.

The local design of retrofitting strategies will also face social challenges glimpsed through the analysis presented. Inadequate materials intersect with other vulnerable conditions, such as deficiencies in water supply or sewage, unstable sources of income, and poverty. For these groups, it is essential to facilitate retrofits that reduce vulnerability while understanding local practises in the provision of energy services. The most crucial aspect is probably the connexion between deprivation and less efficient use of resources, which needs a more inclusive vision.

In sum, we argue for local policy incorporating the local context, regionalising federal and state-level initiatives, but with a culturally and environmentally sound vision, something

that currently is not practised. Future retrofitting strategies should also consider additional domains (water and solid waste management), diverse regimes (housing, non-domestic buildings, urban infrastructure) and multiple stakeholders (government, developers, financiers, and the public). These are also topics for further research related to urban retrofitting in the ZMVO and probably other similar midsize contexts in the developing world.

AUTHOR CONTRIBUTIONS

AM: conceptualisation, policy analysis, survey conduction, validation, and writing. JC: conceptualisation, methodology, survey design, data curation, analysis, writing, review, proof, software, and funding. All authors approved the manuscript for publication.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/frsc.2021.638966/full#supplementary-material>

Supplementary Table 1 | Detailed questionnaire structure and description.

Supplementary Table 2 | Respondents' descriptive statistics.

Supplementary Table 3 | Households' general information (descriptive statistics).

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