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Saving Embodied Carbon Through Strengthening Existing Housing

Contents

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Preface

Build Change is the global leader for systems change in resilient housing. For almost two decades, we have been working to protect people and their livelihoods by preventing housing loss caused by disasters and climate-induced events. We work to transform the systems for regulating, financing, building, and improving houses around the world. Since 2004, Build Change has made over 1 million people and 200,000 buildings safer in over 25 countries.

The people we work with, from homeowners to policymakers and housing financiers, are already experiencing the catastrophic effects of climate change. They are facing more frequent windstorms, a higher proportion of which are more severe, and more intense rainfall with higher flood levels.

Adapting housing to be more resilient to climate change is an essential part of human survival of the climate crisis. But, in addition to adapting to the reality of climate change, we also want to minimize and slow the impact housing has on contributing to the causes of global warming.

Build Change first began working with governments, implementation partners, and homeowners to reuse and improve existing housing in Haiti following the 2010 earthquake near Port-au-Prince. The success of the program led us to apply the same approach to our other programs around the world and focus on improving housing that already exists, rather than building new.

Our experience in improving existing housing and the many benefits of doing so through homeowner-driven implementation models are documented in two existing Build Change publications:

- The Build Change Guide to Resilient Housing, an operational manual with case studies written to communicate our model for making housing resilient and to serve as a practical guide for those who work in pursuit of this goal.
- The Cost of Improving Vulnerable Housing, a comprehensive analysis of the cost of improving vulnerable homes, drawing on close to 1,500 retrofit designs from housing in fourteen countries across Asia, the Pacific, Latin America, and the Caribbean.

Recently we have begun to ask ourselves if we could quantify the environmental benefits. Could we apply established methods for calculating the emissions associated with building materials and construction to the post-disaster contexts in which we work? Could we do the same for preventative housing improvement programs in informal settlements?

The impetus of this study was to answer these questions. The subsequent analysis of our existing data sets has produced a number of important findings and recommendations that we use internally to inform decision-making by our engineers and designers, and externally to better communicate to homeowners and program partners the environmental benefits of improving existing housing. Above all, we want these findings to contribute to the global understanding of the benefits of reusing existing housing by providing data from novel contexts: post-disaster reconstruction and disaster prevention programs for self-built housing in informal settlements.

This report distills these findings into the third in our series of Build Change publications on improving existing housing. It presents the environmental benefits of upgrading existing housing rather than building new, based on analysis of the data set we have developed of our housing improvement programs in six countries around the world.

Acronyms and Key Definitions

Carbon

Embodied carbon: The greenhouse gas emissions associated with materials and construction processes throughout the whole life cycle of an asset.

Environmental Product Declaration (EPD): A third-party verified, standardized document that provides the environmental impact of a product, based on the data from a life cycle assessment.

Greenhouse gas (GHG) emissions/carbon emissions: Emissions of gasses including carbon dioxide, methane, and water vapor that trap heat in the atmosphere. The global warming potential (GWP) of these gasses is measured in CO2e (carbon dioxide equivalent).

Operational carbon: The greenhouse gas emissions arising from all energy and water consumed by an asset in use, over its life cycle.

Housing and Construction

Disaster-resilient housing: Housing that provides a safe, locally appropriate, healthy, and secure space. Moreover, it is affordable and a secure financial investment for its occupants. Resilient housing initiatives are sustainable, adaptable, and scalable. For further details on how Build Change defines resilient housing, refer to the Build Change Guide to Resilient Housing.

Equivalent new construction: A new house with the same structural system and degree of resistance against earthquakes and hurricanes as the retrofit house. The size and architectural details of the house may be different.

Green housing: The application of green building to housing, where green building is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction.

Housing deficit: Calculated as the difference between the population's need for housing and what is available, the housing deficit comprises (1) the "quantitative housing deficit," which refers to the amount of housing that does not exist or is unusable, compared to the number of families that require housing; and (2) the "qualitative housing deficit," which refers to the amount of existing housing that is structurally deficient, lacks basic habitability requirements such as access to services (water, sanitation, and electricity), or is otherwise of inadequate quality.

Informal housing: Housing that has been built outside of the processes recognized by formal construction. For example, it may have been built without the input of a licensed engineer or designer and without a construction permit. Informal housing is used in this guide to refer to the informal process through which the house was constructed. It does not make specific reference or judgment regarding the type of land on which the housing is present, or the ownership of the land or property.

Life safety: A structural design performance level in which the postevent damage state of a structure has damaged components, but retains a margin against the onset of partial or total collapse. Houses that meet the life safety performance level have been designed or retrofitted to meet the required hazard intensity levels defined by building codes.

Lightweight roof: A roof composed of timber or light-gauge steel framing, typically pitched, and covered with roof cladding. Layers of additional waterproofing, insulation, or structural sheathing may also be added.

Retrofit: The reinforcement or upgrading of existing structures to make them more resistant and resilient to the damaging effects of hazards.

Risk reduction: Building improvements that reduce the risk of damage or collapse in the next disaster, but do not target a specific level of performance.

Vertical expansion: Increasing the floor area of a house by adding another story. Vertical expansion interventions include strengthening of the existing first floor structural elements to safely support an additional story, and (if applicable) converting an existing sloping, lightweight roof into a slab.

Figures and Boxes

Executive Summary

The most sustainable house in the world is the home that has already been built.

Assuming, of course, that the house has been made disaster-resilient.

Buildings and construction together account for almost 40 percent of energy-related carbon dioxide emissions, with housing accounting for at least 17 percent of the total[1]. While the benefits of retrofitting housing have long been known for increasing homeowner satisfaction, reducing construction-related costs, and strengthening local economies, little attention has been given to the environmental impact of a housing improvement intervention.

For housing built in informal markets, that is, housing constructed outside of regulation and government oversight, this study answers the question: how much embodied carbon can be saved by improving houses for disaster resilience?

This publication is the latest in a series authored by Build Change on strengthening and upgrading existing housing. Published in 2021, *The Build Change Guide to Resilient Housing: An Essential Handbook for Governments and Practitioners* serves as an operational manual and series of case studies in the operationalization of resilient housing programs. *The Cost of Improving Vulnerable Housing*, published in 2022, outlines the cost benefits and savings associated with improving existing housing for resilience.

As the third in this series, and informed by cases drawn from Build Change's work in Colombia, Haiti, Honduras, Nepal, Philippines, and Sint Maarten and a total of 335 built projects, *Saving Embodied Carbon Through Strengthening Existing Housing* provides compelling evidence that **improving existing housing significantly avoids carbon emissions in the housing construction value chain, thereby having substantial implications for achieving net zero in the built environment.**

Our intention is to contribute to global knowledge and research on the embodied carbon resulting from housing retrofits, upgrades, and improvements as well as new housing construction. In doing so, stakeholders across the housing value chain, including engineers and construction officials, policymakers, financiers, and advocates, can advance sustainable solutions to reduce the qualitative housing deficit and ensure provision of resilient housing.

Key findings include:

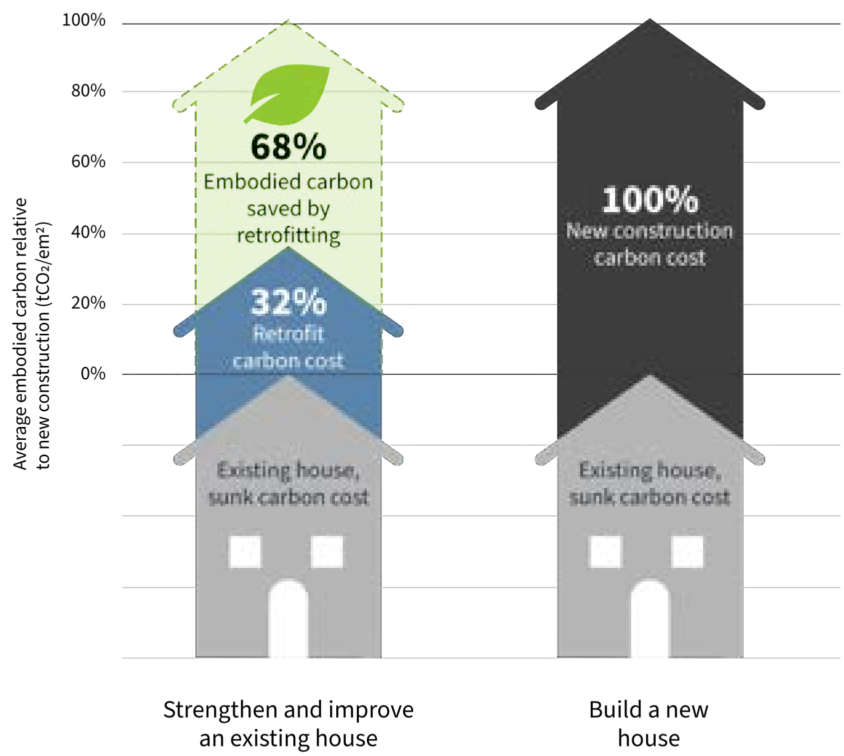
- **Improving a house instead of building a new one saves two-thirds of embodied carbon of an equivalent new house, and, on average, saves 18 metric tons of carbon dioxide.** For the same embodied carbon budget of one new house, more than three houses can be improved and made safer.
- **Even if vertical expansion is included in the intervention, creating an additional living space or unit, it is still more carbon-efficient to improve existing housing rather than build new.** With vertical expansion (i.e. adding a second story), improving existing housing still uses, on average, 47 percent less embodied carbon than an equivalent new house. In some cases, vertical

[1] United Nations Environment Programme (2021). *2021 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector.* Nairobi

expansion simply makes the existing home larger to accommodate growing families or home businesses. In other cases, vertical expansion creates an additional, independent housing unit. By transforming one housing unit into two, the emissions savings are doubled.

- **It is more carbon-efficient to improve an existing house *before* a disaster—even when the house is also expanded—than wait until it is destroyed and has to be rebuilt.** Embodied carbon savings for a preventative upgrade are, on average, 61 percent higher than a post-disaster upgrade (without expansion). When the house is also expanded vertically, savings are still 26 percent higher if the upgrade is done preventatively.

Figure 1: The Costs of Inaction



Policymakers play a critical role in shaping the regulatory environment for prioritization of embodied carbon reduction in the housing sector through retrofitting. Based on the findings from this study there are a number of important actions that can be taken to advance overall resilience and embodied carbon savings in the housing sector. Most critically, these include:

1. **Retrofit houses to withstand disaster.** Policymakers should prioritize retrofitting existing housing as an effective strategy for both climate change adaptation ***and*** mitigation. The best way to balance the urgent needs for more housing, resilient housing, and green housing, while minimizing greenhouse gas (GHG) emissions, is to upgrade the existing housing stock.
2. **Act now!** Governments and homeowners should retrofit preventatively, before a disaster, to save even more emissions. The additional materials required for building repair in post-disaster scenarios significantly increases the emissions. Policies should incentivize mitigation before the next disaster.

3. **Advance actions which prioritize housing upgrades within climate commitments, such as NDCs or building sector roadmaps, as well as national urbanization frameworks.** With the next round of updates to Nationally Determined Contributions (NDCs) in 2025, the moment is ripe for integrating ambitious goals into climate planning. Governments should include housing upgrade plans within national frameworks for urban development and climate mitigation and adaptation, as well as within provisions for incremental upgrading within building codes. Advancing data through this study, and subsequently promoting action and leadership to reduce embodied carbon in the built environment—and in housing specifically—will be critical to shape the future of mitigation efforts, as well as provide the housing needed to meet the increasing requirements of a changing environment and global population.

1.0 Introduction: Two Conflicting Global Challenges

Globally, we need more housing—and we need better housing.

UN-Habitat estimates that 40 percent of the world's population will need access to adequate housing by 2030, which translates into a demand for 96,000 new housing units every day.[2] Growing populations are driving a need for more housing in absolute terms. This is particularly true in cities, because of unceasing rural to urban migration.

This quantitative deficit goes hand in hand with the *qualitative* housing deficit, meaning there is an equal or greater need to improve the units that already exist. For example, neighborhoods may need connection to fresh water and sanitation infrastructure, or buildings may need to be strengthened and improved to better withstand earthquakes and climate extremes.

A critical component of reducing the qualitative housing deficit is increasing disaster resilience. Natural hazards alone do not cause disasters. Disasters develop when a natural hazard occurs in a location of high population exposure, and are exacerbated by social, financial and environmental vulnerabilities. The many barriers to resilient housing, including those caused by policy, money, and technology, mean it is common for housing to have been inadequately designed or built to resist natural hazards. Seventy-seven percent of fatalities from the deadliest earthquakes in the last 100 years were due to the collapse of masonry structures.[3]

Unfortunately, the risk from natural hazards is not static. Climate change is creating new hazards, exacerbating existing ones,[4] and multiplying the exposure to hazards.[5] Furthermore, the growing climate risk does not affect all people equally. Countries and populations with minimal historical emissions—such as small island developing states and indigenous communities—are disproportionately affected by the adverse effects of climate change,[6] resulting in serious threats to their homes.

We also need to significantly reduce both the embodied and operational greenhouse gas emissions associated with housing.

The UN Environment Global Status Reports conclude that buildings and construction together account for almost 40 percent of energy-related carbon dioxide emissions, with housing accounting for at least 17 percent of the total (See Figure 2)[7] . To meet global climate ambitions set out in the Paris Agreement, the

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[2] UN-Habitat, *Housing* (2022). https://unhabitat.org/topic/housing

[3] The World Bank, *Roadmap for Resilient Housing: The Path to Livable, Disaster and Pandemic Resilient Housing*, (Washington, D.C.: Global Program for Resilient Housing, 2020).

[4] NOAA GFDL, *Global Warming and Hurricanes: An Overview of Current Research Results* (2023) https://www.gfdl.noaa.gov/global-warming-and-hurricanes/; Very intense refers to Category 4 or 5 levels.

[5] Carbon Brief. *Mapped: How climate change affects extreme weather around the world* (2022). https://www.carbonbrief.org/mapped-how-climate-change-affects-extreme-weather-around-the-world/

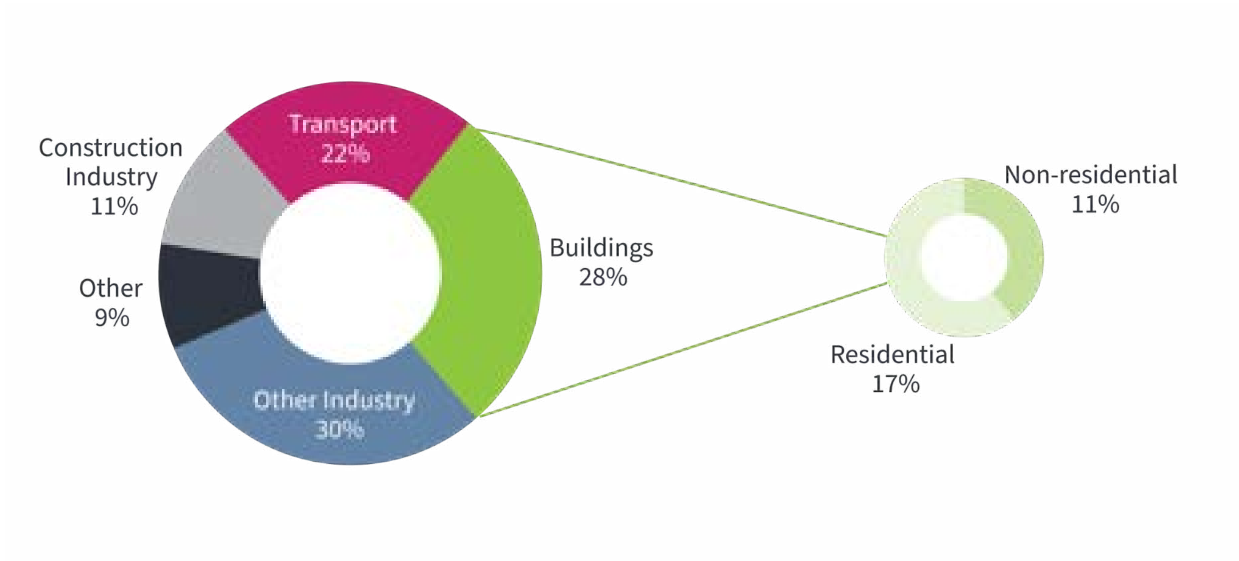
[6] UNFCCC, *Small Island Developing States and Climate Change* (2005). https://unfccc.int/resource/docs/publications/cc_sids.pdf

[7] The 2017 Global Status report, with data from 2015, concluded buildings and construction account for 39 percent. This dropped slightly to 37 percent in the 2021 report, with data from 2020. The reduction is noted to have been a temporary result of the COVID-19 pandemic, rather than a permanent reduction due to changing practices; United

global buildings and construction sector must almost completely decarbonize by 2050. The energy intensity per square meter of the global buildings sector needs to improve on average by 30 percent by 2030 (compared to 2015).

At the same time, Dr. Fatih Birol, head of the International Energy Agency, recently noted that the world is expected to build 230 billion square meters of new construction over the next 40 years—adding the equivalent of the city of Paris to the planet every single week.[8]

Figure 2: Share of global energy-related CO2 emissions by sector



Source: United Nations Environment Programme

Emissions associated with buildings and construction are split into two groups: embodied carbon emissions and operational carbon emissions.

> *Embodied carbon* refers to the emissions associated with materials and construction processes over the whole life cycle of a building.
>
> *Operational carbon* refers to the emissions associated with the energy used to operate a building, such as heating, lighting, and power for appliances.

To date, the global focus has been to prioritize reductions in operational emissions from buildings and construction, a logical initial response when operational emissions have traditionally accounted for a higher proportion of total emissions. Globally, investment in the energy efficiency of buildings is rising, reaching more than USD 180 billion in 2020—a 40 percent increase since 2015.[8] Regulation is also increasing: 63 percent of countries now include measures for energy efficiency improvements in

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Nations Environment Programme (2021). *2021 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector.* Nairobi

[8] UN Environment and International Energy Agency (2017) *Towards a zero-emission, efficient, and resilient buildings and construction sector. Global Status Report 2017.* https://worldgbc.org/wp-content/uploads/2022/03/UNEP-188_GABC_en-web.pdf

buildings as part of their Nationally Determined Contributions and 81 countries now have mandatory or voluntary building energy codes (compared to 62 countries in 2015).[9]

However, because focus has been on operational instead of embodied carbon emissions, embodied emissions now account for a much larger proportion of total building lifetime emissions. In some countries, embodied carbon may soon approach 100 percent of the total and can already account for 40–70 percent of whole life carbon in a new low-carbon building.[10]

How do we balance the needs for more housing, resilient housing, and green housing?

The urgent need for more and better housing often appears to be at odds with demanding schedules for emissions reductions targets in buildings and construction. Adequate housing is an essential precursor for economic prosperity, health and wellbeing, and equitable development. But if no changes are made to housing production, the environmental cost of providing for such a large proportion of the global population will be disastrously high.

Inherent to disaster-resilient housing is resistance against damage from natural hazards such as hurricanes, floods, fires, and earthquakes. However, the additional demands these kinds of loads place on a structure are not immediately complementary to efforts towards lower carbon, more efficient design. There is growing evidence that when the full life cycle and life span of a building is considered, it is neither sustainable nor economical to build structures that will be damaged beyond repair during expected hazard events, and thus require complete replacement with new building materials.

Box 1: Embodied Carbon and Earthquakes in New Zealand. *Following the 2010-2011 Canterbury, New Zealand earthquakes, 60 percent of multistory buildings in the Christchurch central business district were demolished. Using a dataset of 142 demolished concrete buildings, researchers at the University of Auckland found that the total embodied carbon, now beyond reuse and deposited in a landfill, was equivalent to the emissions from the electricity purchased by 20 percent of the dwellings across the country in a year.*[11]

Harnessing the potential of "Build Less"

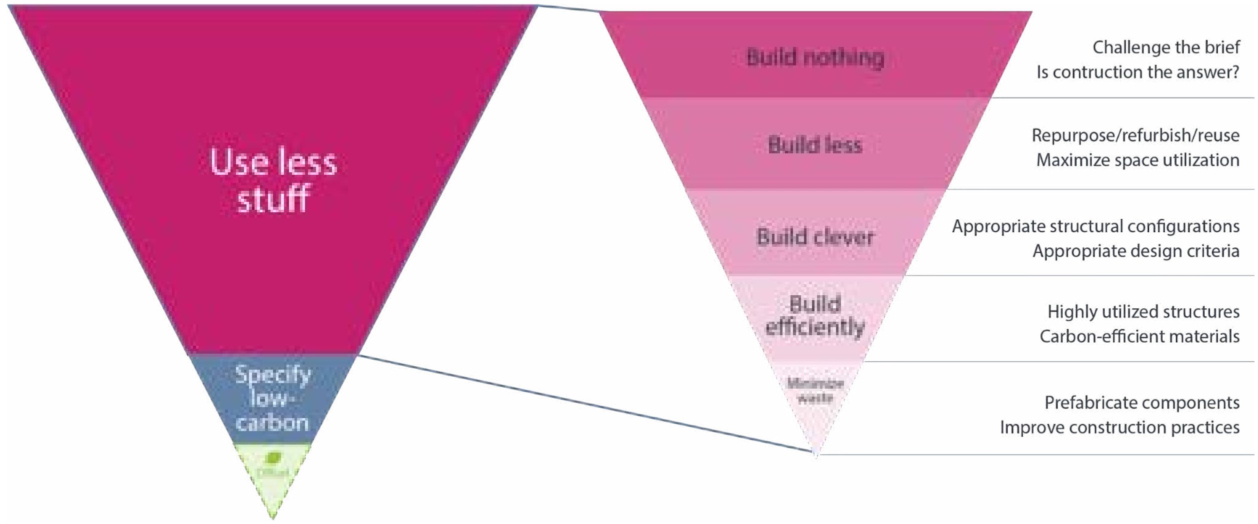
In the Hierarchy of Net Zero Design (see Figure 3), enormous potential exists to reduce embodied carbon in the built environment by applying the "Build Less" approach to housing. This category, which has the second highest potential to create savings next to "build nothing", includes repurpose, refurbish, and reuse. Strengthening and improving an existing home to withstand disaster fits perfectly in this category.

[9] UNEP, *2021 Global Status Report for Buildings and Construction*

[10] IStructE (2021). *Design for zero.* The Institution of Structural Engineers, London, United Kingdom. https://www.istructe.org/resources/guidance/design-for-zero/

[11] Gonzalez, R.E., Stephens, M.T., Toma, C. et al. *Incorporating potential environmental impacts in building seismic design decisions.* Bull Earthquake Eng 21, 4385–4428 (2023). https://doi.org/10.1007/s10518-023-01686-y

Figure 3: The Hierarchy of Net Zero Design



Source: IStructE (IStructE, 2022)

2.0 Overview of the Dataset and Analysis Approach

This report presents a first-of-its-kind international data set on the embodied carbon savings impacts of improving existing housing to withstand disaster.

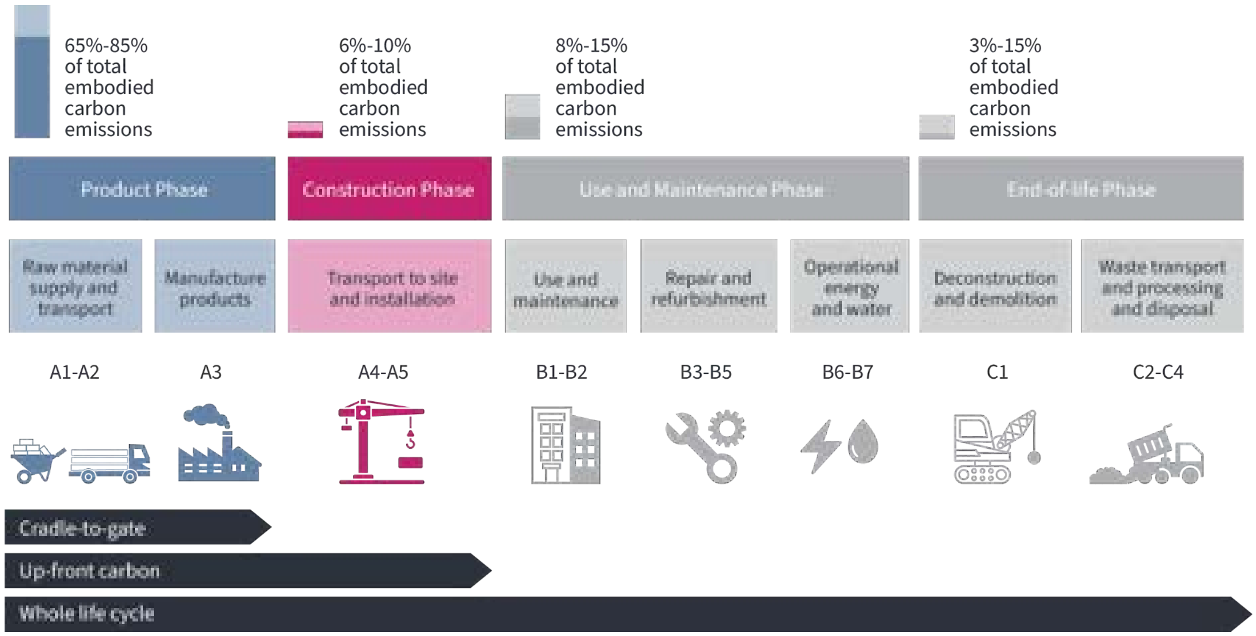
The dataset spans six countries across four continents. The embodied carbon savings are estimated by comparing 275 existing home strengthening projects with 60 new disaster-resilient housing projects in the same countries. All 335 homes have been built or retrofitted by Build Change or our partners, meaning the analysis was based on the final, measured quantities of materials that went into each house.

Comparing the home retrofits against disaster-resilient new construction was the favored approach for a number of reasons:

- **In most cases, new construction is the most likely alternative to retrofitting.** In both post-disaster and prevention contexts, the misperceived challenges of improving existing housing most often result in governments, the private sector and aid agencies opting to build new rather than improve existing housing.
- **The relative approach standardizes the results and allows compilation and comparison at a global scale.** Build Change's retrofit interventions vary considerably depending on the local context, but by always comparing the retrofit to an equivalent new construction we are able to aggregate the results and draw global conclusions.
- **Considering the results relative to a baseline addresses many of the challenges of uncertain or absent data.** In the countries highlighted in this study, there is a scarcity of data on embodied carbon of building materials. By using the same data for emissions calculations of retrofit and new construction houses, this analysis ensures that the emphasis is on the difference between the two scenarios.

Our analysis considers the "upfront carbon", referred to as lifecycle stages A1 to A5 in Figure 4, for both the retrofit homes and the new construction homes. Whether a home is disaster resilient because it was retrofitted or newly built does not significantly impact the emissions associated with the use and end-of-life phases, so the emissions associated with stages B and C are canceled out when comparing retrofit with new construction.

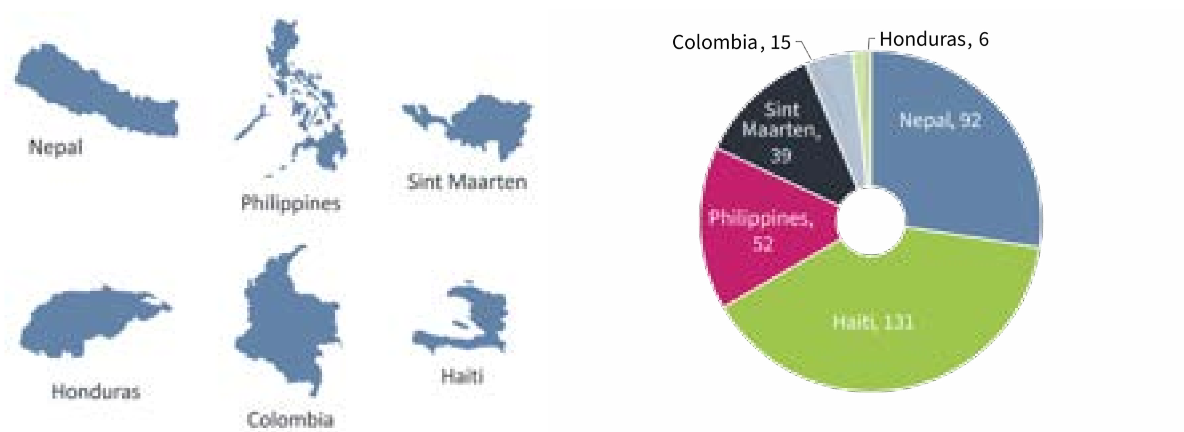
Figure 4: Building Life-Cycle Assessment Phases



Source: RMI

To account for differences in the data sample size from different countries, the houses were grouped into 16 different design groups. Every house within a design group shares key characteristics, such as location, construction type, performance target, hazards considered, and disaster context. Sample designs within the same design group were averaged to determine an overall representative set of carbon costs for each group.

Figure 5: Countries and Their Respective Sample Size (Number of Houses) Represented in Dataset



Source: Build Change

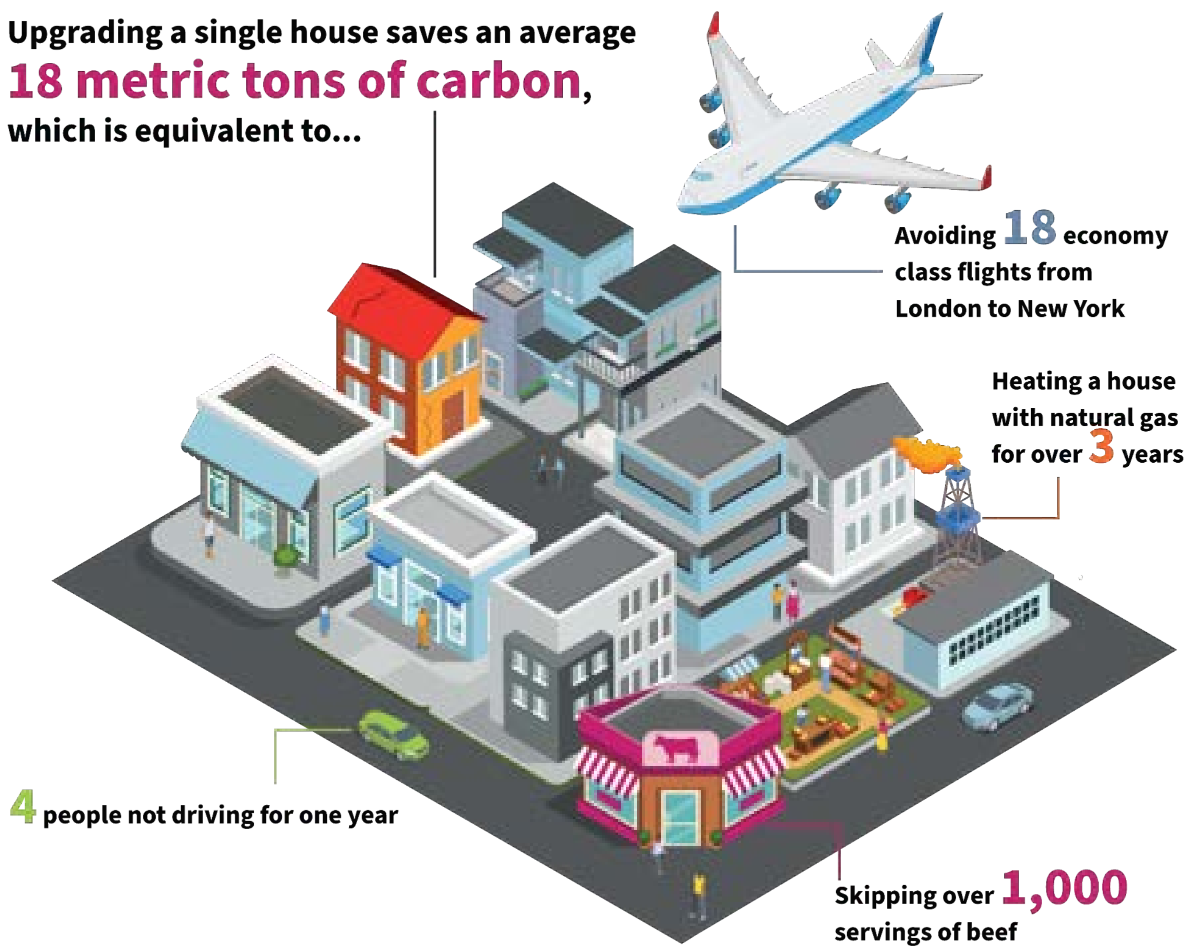
3.0 Key Findings

1. **Improving an existing house, instead of building a new one, saves 18 metric tons of carbon dioxide.**

On average, 18 metric tons of carbon dioxide are saved per house.

This is more than one person's total annual emissions in the US or 60 people's total annual emissions in Haiti.[12]

Figure 6: The Relative Cost of Embodied Carbon Savings in a Single House



Source: Build Change

2. **Each home improved saves over two-thirds of the embodied carbon generated by an equivalent new house.**

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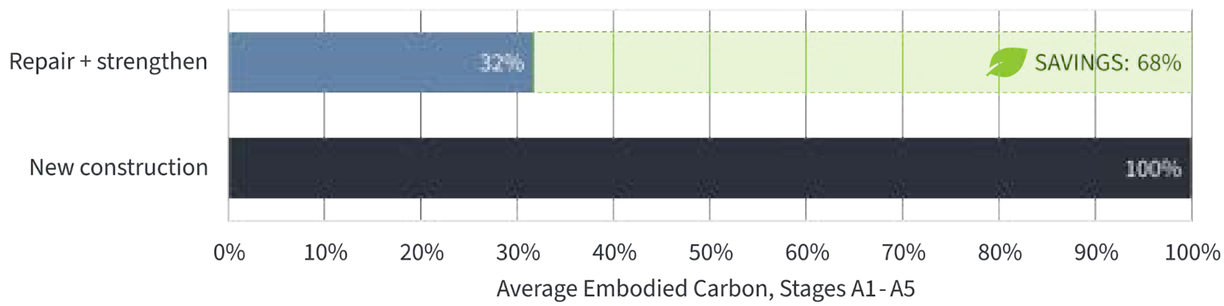
[12] 14.7 metric tons emitted per capita in the US, 0.3 metric tons emitted per capita in Haiti, 2019 data (World Bank, 2023)

Reusing and improving existing housing is a way to balance the urgent need for more, better quality housing with greenhouse gas emissions reductions. Strengthening existing housing uses just 32 percent of the embodied carbon of an equivalent new house on average. This means that for the same embodied carbon budget of one new house, three houses can be improved and made safer.

Figure 7: Average Embodied Carbon in Home Improvements, Relative to Equivalent New Construction

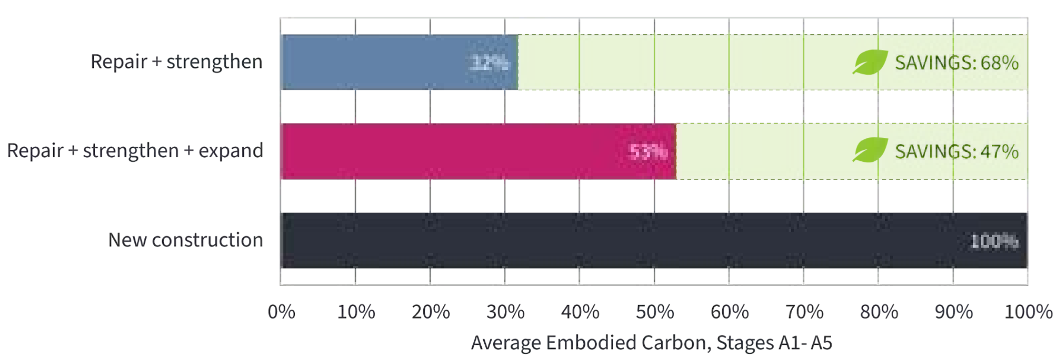


3. Even if vertical expansion is included in the intervention, it is still more carbon-efficient to improve existing housing rather than build new.

With vertical expansion to create an additional living space or unit (e.g. a second story), strengthening existing housing still only uses 53 percent of the embodied carbon of an equivalent new house. In cases where the expansion creates an additional housing unit, the savings are doubled.

For many homeowners with limited financial resources, strengthening their home for increased hazard resistance takes a lower priority than habitability improvements or meeting the daily needs of their family. Incentives—such as the safe addition of a second story—are often integral to reaching wide-scale adoption of home improvement programs. At a wider scale, vertical expansion of homes increases the supply of available safe housing and supports urban densification, which minimizes land consumption, increases the operational energy efficiency of housing units, and reduces emissions from transportation.

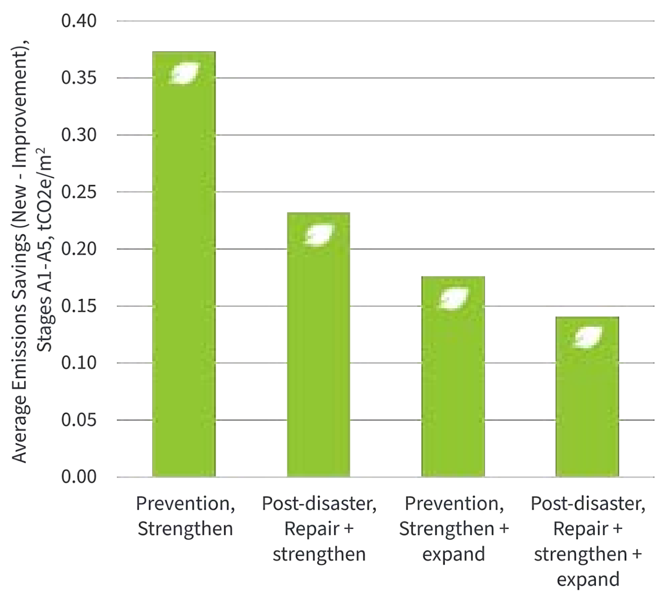
Figure 8: Average Embodied Carbon in Home Improvements with Vertical Expansion, Relative to Equivalent New Construction



4. **It is more carbon-efficient to improve an existing house *before* a disaster than after—even when the house is also expanded.**

Post-disaster home improvements typically use a lot more material for repairs. As a result, the embodied carbon savings for a preventative upgrade are on average 61 percent higher[13] than a post-disaster upgrade (without expansion). When the house is also expanded vertically, savings are still 26 percent higher if the upgrade is done preventatively.[14]

Figure 9: Emissions Savings by Intervention Type and Timing



Improving a home preventatively, before a disaster, also has considerable financial and social benefits. In 2021, Build Change published the findings from a detailed cost analysis of global projects, which used much of the same data as this embodied carbon analysis. It found that the construction costs to improve existing houses were approximately 1.6 times lower, on average, in a prevention context than in a post-disaster context, and the amount spent on structural condition repairs was almost six times less before a disaster than after.

5. **Not all home improvements are equal—the emissions associated with interventions vary depending on several factors.**

The Build Change Guide to Resilient Housing details with numerous examples the many considerations when designing a home improvement program, of which minimizing embodied carbon is unlikely to be the top priority to key stakeholders. However, the decisions made at the start of a housing program can have a significant impact on the overall emissions savings. The embodied carbon associated with home improvement interventions depends on many factors, and an appreciation of how decisions impact the potential emissions savings is an essential first step.

As the last two findings have shown, the emissions savings depend on the:

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[13] Average savings for house upgrade post-disaster: 0.22 tCO_2e/m^2; average savings for house upgrade in a prevention context: 0.37 tCO_2e/m^2. Does not include houses with expansion.

[14] Average savings for improvement and expansion post-disaster: 0.14 tCO_2e/m^2; average savings for improvement and expansion in a prevention context 0.18 tCO_2e/m^2.

- **Timing**, whether performed preventatively or post-disaster
- **Scope of the intervention**, particularly if vertical expansion is desired (see Colombia, Haiti, and Honduras case studies for more details).

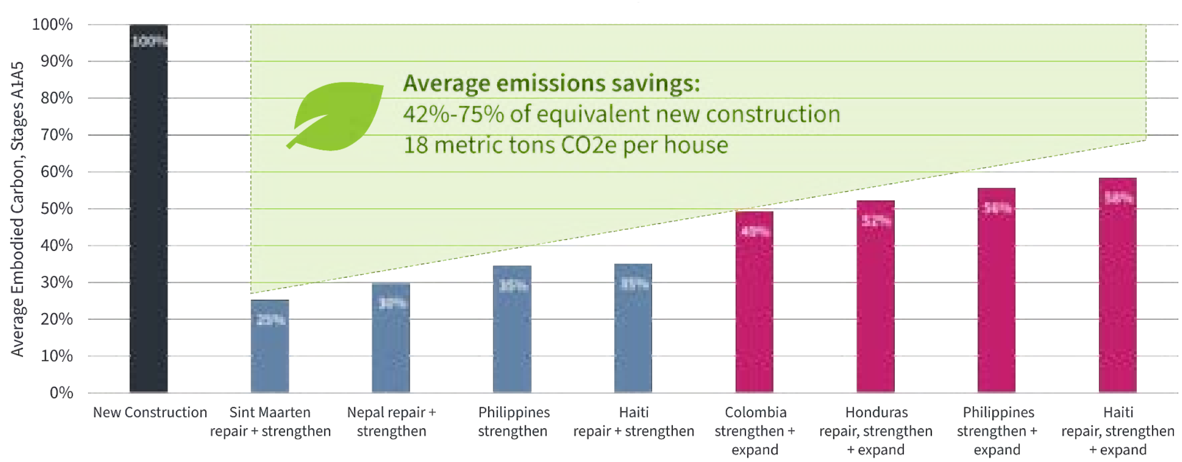
The detailed case studies show how a number of other factors can influence the extent of emissions savings, including:

- **Condition of the existing building**, including damage due to lack of maintenance
- **Quality of the existing design and construction**, which influences the number and type of strengthening interventions required in the retrofit (see Haiti and Sint Maarten case studies)
- **Materials of existing building**, as often these limit the materials of the retrofit intervention (see Nepal case study)
- **Design criteria**, including the hazards, and desired or required performance level of the building against those hazards (see Sint Maarten case study)
- **Homeowners' preferences**, in particular the type of roof (most often choosing between a concrete flat slab roof or a pitched, timber framed roof), but also their decisions on features such as non-structural plaster (see Colombia case study)
- **Location**, which affects the source and transportation of retrofit materials (see Philippines case study)

Interestingly, the size of the house (measured by floor area) was not a significant factor in the emissions of an improvement intervention. This is thought to be because larger houses are often first designed and built to higher standards, and it means that larger houses should not be precluded from strengthening programs solely on the basis of their size.

The impact of these factors can be seen in the embodied carbon emissions savings from Build Change home improvement programs, which varied between 42 percent and 75 percent as compared to new construction.

Figure 10: Home Improvement Emissions by Program, Relative to New Construction



The highest savings of 75 percent were for one of the Sint Maarten design groups, where program *design criteria* meant that the majority of the homes were strengthened for risk reduction rather than a full life safety performance level. The *condition and materials of the existing houses* were also typically of higher quality than in other countries.

The lowest savings of 42 percent were in Haiti for the vertical expansion design group. *The condition and quality of the existing buildings* were poor, the *design criteria* relatively stringent due to the very high seismic and hurricane risk, and the *scope of the intervention* included vertical expansion.

For further details on Sint Maarten, Haiti, and all other country programs, see the Detailed Country Case Studies.

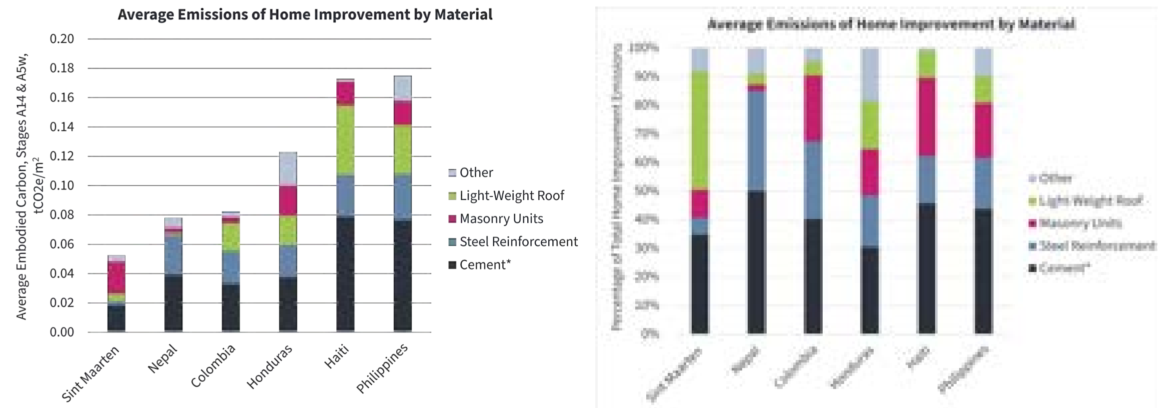
6. Cement and steel account for 60 percent, on average, of all home improvement emissions.

Build Change's structural home improvements are typically limited to only six or seven principal materials based on the common locally available skills and materials where the programs have operated. These are concrete, consisting of cement, sand, gravel, and water; steel reinforcement; masonry units, most commonly fired clay or concrete blocks; metal roof sheets; and timber or hollow steel sections for roof framing. However, Figure 11 shows that the emissions associated with these materials are far from equal. Averaging emissions across the six countries, steel and cement account for over 60 percent of embodied carbon emissions.

Figure 11: Average Emissions From All Countries By Material

In each country, cement and steel account for at least 40 percent of all emissions. Figure 12 shows how in countries where concrete block walls are prevalent, such as Haiti and the Philippines, cement and steel account for over 80 percent of embodied carbon emissions.

Figure 12: Average Emissions of Home Improvement by Material, in tons of CO2e and as a percentage of home improvement emissions



*Cement includes aggregates for Colombia and Sint Maarten; for all other countries aggregates are included under Other.[15]

Masonry is a popular building material for housing throughout the world. Homeowners opt for masonry homes for many reasons: the materials and labor are easily available on the local market, it is affordable, and it is familiar and part of the culture. Compared to other housing construction systems, masonry can have improved resistance to fires and to flying debris during wind storms; it can be more secure against intruders; and it has a higher thermal mass, which reduces thermal gain in hot climates and keeps families cooler.

However, when masonry houses are under-reinforced or unreinforced, such as those considered in this study, they are poorly suited to resist the effects of earthquakes and windstorms. 77% of fatalities from the deadliest earthquakes in the last 100 years are associated primarily with the collapse of masonry structures.[16]

Strengthening vulnerable masonry houses typically requires the use of reinforced concrete (which is made from cement and steel reinforcement, as well as other materials) as it improves structural performance while also being affordable to homeowners, available in local markets, and familiar to local builders.

[15] In its simplest form, concrete is made by mixing cement, aggregates (sand and gravel), and water. For the houses in this study, concrete was made in two different ways. For the majority of houses, the constituent materials were purchased separately and mixed on site; for houses in Colombia and Sint Maarten, the concrete was mixed offsite at a batching plant and then delivered ready to be poured. When concrete is batched off-site, the emissions associated with the aggregates are reported together with the cement. Concrete aggregates typically account for a very low proportion of total home improvement emissions (2–5 percent).

[16] The World Bank, *Roadmap for Resilient Housing:The Path to Livable, Disaster and Pandemic Resilient Housing*, (Washington, D.C.: Global Program for Resilient Housing, 2020).

4.0 Recommendations

The recent focus on reduction of carbon in the built environment has centered primarily on reduction of operational carbon. While this remains critical to advance climate mitigation, the findings of this study contribute to increasing focus on embodied carbon reduction as an equally important solution for both climate mitigation and adaptation.

Policymakers play a critical role in shaping the regulatory environment for prioritization of embodied carbon reduction in the housing sector through retrofitting. There are a number of important actions that can be taken to advance overall resilience and embodied carbon savings in the housing sector.

1. Retrofit houses to withstand disaster.

Policymakers should prioritize retrofitting existing housing as an effective strategy for both climate change adaptation ***and*** mitigation.

The best way to balance the urgent needs for more housing, resilient housing, and green housing, while minimizing GHG emissions, is to upgrade the existing housing stock. Improving an existing house instead of building a new one saves over two-thirds of the embodied carbon generated by an equivalent new house. Even if the house is vertically expanded to add a new second story, it still only uses half the embodied carbon of an equivalent new house.

In addition to the emissions savings from retrofitting, there are also known to be significant cost savings. On average, in the 2022 study The Cost of Improving Vulnerable Housing, Build Change found the cost of retrofitting a house was 23 percent of the cost of building new in the same location.

Furthermore, a house does not have to be retrofitted to full building code compliance level to see benefits in terms of disaster resistance. Where legally permitted, risk reduction improvements can improve building safety at much lower financial and environmental costs: life safety interventions cost 17 percent more than risk reduction interventions[17] and, in Sint Maarten, saved double the emissions.

2. Act now!

Governments and homeowners should retrofit preventatively, before a disaster, to save even more emissions.

The additional materials required for building repair in post-disaster scenarios significantly increases the emissions. For a house without expansion, the embodied carbon savings for a preventative upgrade are on average 61 percent higher than a post-disaster upgrade. In other words, waiting until after a disaster to retrofit a home reduces the savings by 1.6 times.

Financially, it is also significantly cheaper to retrofit preventatively rather than after a disaster: construction costs to improve vulnerable housing were found to be 1.6 times lower in a prevention context than a post-disaster context.[18]

[17] *The Cost of Improving Vulnerable Housing: Recommendations for Investments in Housing Resilience from an Analysis of Global Project Data.* Denver, CO: Build Change, 2022.
[18] ibid.

3. Design retrofits appropriately and efficiently

Engineers can increase savings generated through retrofitting existing housing by designing appropriately and efficiently.

For the masonry buildings that make up the large majority of structures considered in this study, the emissions from reinforced concrete far outweigh all other materials. However, completely eliminating the use of reinforced concrete in home strengthening interventions is not feasible. Reinforced concrete is frequently preferred by homeowners, and the only material readily and affordably available with which the local labor force already has the expertise to build resilient homes.

There are several ways that reinforced concrete can be used more appropriately and efficiently to support emissions reductions. Examples of appropriate design criteria include accurate determination of the hazard exposure and selection of an appropriate performance level. Designing efficiently can include:

- Ensuring reasonable factors of safety are used and the building or certain elements within the building are not over-designed for the anticipated loads;
- Considering, where available in the local market, the use of lower-carbon alternatives, such as partially replacing cement with substitute materials such as pulverized fuel ash (PFA) or ground granulated blast-furnace slab (GGBS) (or newer alternatives);
- Maximizing use of the existing structure; and
- Minimizing waste, for example by designing the building geometry to suit standard material dimensions.

4. Increase data available on embodied carbon in housing.

One of the major challenges in undertaking upgrading projects or retrofits within infrastructure, especially housing, is a lack of data around embodied carbon. This is particularly true in the Global South. Life cycle assessments (LCA) that quantify the potential savings generated should be introduced as an additional means to assess the relative benefits of different housing programs, both in post-disaster or preventative strengthening contexts. LCAs should be standardized and publically reported. This can serve as a useful resource for any publicly funded or subsidized upgrading projects to demonstrate the environmental impacts, as well as for investors into privately owned housing to demonstrate the overall positive impact of the investment. Homeowners would also benefit from this information as a choice tool to determine how they prioritize upgrade programs.

5. Advance actions which prioritize housing upgrades within climate commitments, such as NDCs or building sector roadmaps, as well as national urbanization frameworks.

Following on the heels of the Paris Agreement, the next decade will be critical in refining and addressing gaps in climate commitments. With the next round of updates to Nationally Determined Contributions (NDCs) in 2025, the moment is ripe for integrating ambitious goals into climate planning. Governments should include housing upgrade plans within national frameworks for urban development and climate mitigation and adaptation, as well as within provisions for incremental upgrading within building codes. Any commitments will require adequate investments via loans, public resources, grants, or other financing mechanisms, which should be reflected in planning processes.

6. **Recognize the role of city and regional actors in upgrading housing.**

Planning around housing upgrades is important for both national actors and sub-national governments, including regions and cities. Various mechanisms, such as city roadmaps, sector roadmaps, or other planning goals, should integrate a “retrofit-first approach” where appropriate, both to maximize efficient use of resources (see *The Cost of Improving Vulnerable Housing*) and reduce environmental impacts. This also requires adequate financing—through public and private sources—of these initiatives advanced by non-state actors, including city and regional actors, as well as other actors across the housing value chain.

7. **Educate housing officials and decision-makers about the environmental impacts of retrofitting.**

Organizations, including Build Change, have advocated for upgrading housing for decades. Educating housing officials about the environmental impacts of retrofitting is critical to ensure widespread adoption of retrofit-friendly policies and projects. Capacity-building programs for public sector officials should include information on the benefits of upgrading housing, including the environmental, cost, economic growth, and sustainable development benefits as an alternative to new construction projects.

5.0 Detailed Findings—Program Case Studies

5.1 Habitability Improvement in Colombia: Significant Benefits to Homeowners at Minimal Environmental Cost

Location: *Bogota, Colombia*
Context: *Prevention*
Number of houses analyzed: *14 retrofit, 1 new construction*
Hazards: *Earthquake*
Building type: *Horizontally perforated fired clay masonry, unreinforced or partially confined, with lightweight or reinforced concrete (RC) slab roof*
Intervention scope: *Retrofit, and vertical expansion to add a second story*
Performance level: *Life safety*

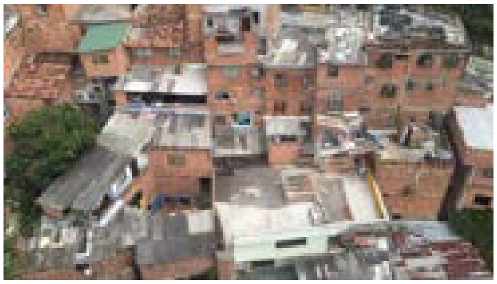
Program details:

Build Change's work in Colombia began in 2013. It was our first program to fully focus on disaster prevention, rather than also including post-disaster reconstruction. Over the last decade, Build Change has carried out a wide variety of projects in the country, working with homeowners, and local and national governments. One of our more recent programs is in Bogota, with the local government and its *Plan Terrazas* program, which provides subsidies to households for housing improvements,[19] including:

- **Disaster mitigation measures:** Preventative strengthening of the main structural elements of the house to increase resistance against future earthquakes. For example, by adding new ring beams above all walls, and adding reinforced concrete confining columns at wall intersections and window and door openings.
- **Structural condition repairs:** Repair of damaged elements, such as reinforced concrete roof slabs that are cracked or replacing masonry walls that are unfinished or damaged.

[19] *Plan Terrazas*. www.habitatbogota.gov.co/proyectos-estrategicos/plan-terrazas

- **Habitability improvements:** Measures to improve the well-being and quality of life of the inhabitants, such as adding new windows for natural light and ventilation, ensuring the roof is watertight, and providing additional security measures on exterior doors and windows.
- **Vertical expansion:** The first floor of the house is strengthened to safely accommodate a new second story. If the existing house has a lightweight roof, this is replaced with a reinforced concrete slab. A new second story is added.



Typical informal housing in Bogota

Ercilia Suarez's house before (left) and after (right) retrofit and vertical expansion under the city of Bogota's Plan Terrazas program, supported by technical assistance from Build Change.

The vast majority of informal housing in Bogota follows a very similar design and construction style. Homes are built incrementally, with fired clay perforated blocks and reinforced concrete. Initially, the houses are single-story with a lightweight roof (pitched metal sheets, supported by timber or steel framing), and the brick walls may be unreinforced or confined masonry.

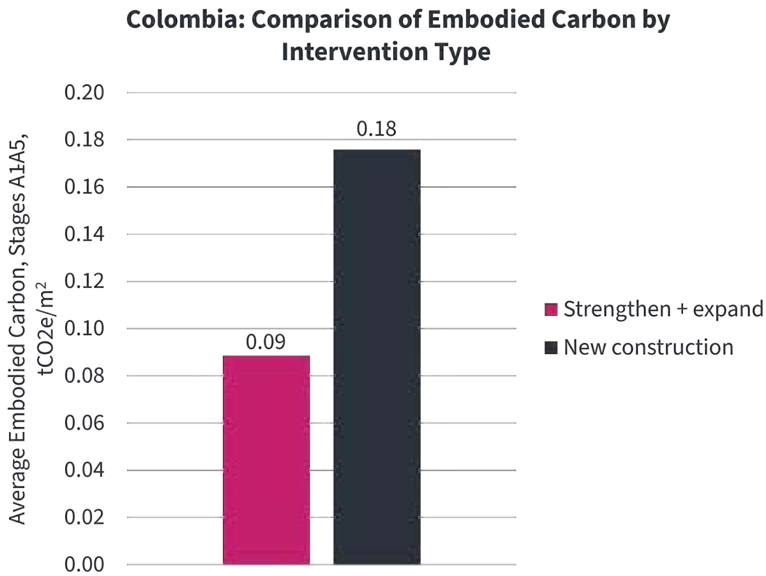
Once the homeowner can afford to expand, they will change the roof to a reinforced concrete slab and add a second story, again using fired clay bricks for the walls, possibly confined by reinforced concrete elements. If funds allow, this process of vertical expansion often continues for several more stories.

The *Plan Terrazas* program is exclusively for single-story homes. The program concept is to strengthen the existing first floor to resist loads from earthquakes and vertical expansion, and to build a new second floor. If the existing house does not have a slab roof already, the lightweight roof is converted to a slab. The final, two-story building has a lightweight roof.

Findings:

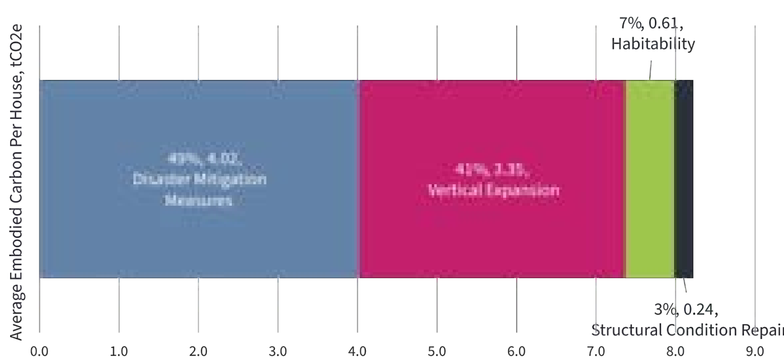
Overall, home improvements in Bogota save 51 percent of the emissions of equivalent new construction. On average, strengthening existing homes in Colombia for disaster mitigation, repair, habitability, and vertical expansion saves 9.8 metric tons of carbon dioxide per house (0.09 tons per square meter).

Figure 13: Average Embodied Carbon by Intervention Type in Colombia



Habitability improvements are often the most desirable for homeowners, and account for just 7 percent of the total embodied carbon. Habitability improvements are often an essential incentive for homeowners to make disaster mitigation upgrades. Simple improvements, such as a new, secure door or paint for the walls are much more tangible outcomes than reduced earthquake risk and can make a positive difference to homeowners' everyday lives. As these habitability improvements contribute very little to the total embodied carbon of the home improvement intervention, they should continue to be used as incentives to increase wide-scale adoption of home improvement programs.

Figure 14: Breakdown of Embodied Carbon in Home Improvements in Colombia



5.2 The Emissions Savings From Strengthening and Expanding Homes in Post-Earthquake Haiti

Location: *Port-au-Prince (2010–2018) and Les Cayes and surrounding areas (2021–2022), Haiti*
Context: *Post-disaster (2010 and 2021 earthquakes)*
Number of houses analyzed: *78 retrofit, 53 new construction*
Hazards: *Earthquake, wind*
Building type: *Concrete block masonry with lightweight or reinforced concrete slab roof*
Intervention scope: *Repair and retrofit, some with vertical expansion to add a second story*
Performance level: *Life safety*

Program details:

Build Change's Haiti program has included numerous housing retrofit projects over the past decade. All projects have been in a post-disaster context following the 2010 and 2021 earthquakes, which means that the interventions include both repair and reconstruction of damaged elements as well as strengthening of the existing structural system. For example, in addition to rebuilding collapsed walls and repairs to the roof, the scope of work may also include new tie columns at wall intersections and new reinforcement around window openings.

The houses are a mix of one- and two-story masonry buildings with timber hip or concrete slab roofs. All suffered damage during an earthquake and require repairs as well as structural strengthening. Repair interventions include: reconstruction of masonry walls, reconstruction of lightweight (timber-framed, metal sheet clad) roofs, construction of hollow core concrete block slab, and repairs to damaged concrete slab roofs. The most common structural strengthening measures are new reinforced concrete confining columns at walls ends and intersections, and either side of door and window openings.

Before (left) and after (right) Build Change technical and financial support for repair and retrofit of Aurore Medard's home

Before (left) and after (right) Build Change technical and financial support for repair and retrofit of Naomie Gobert's home

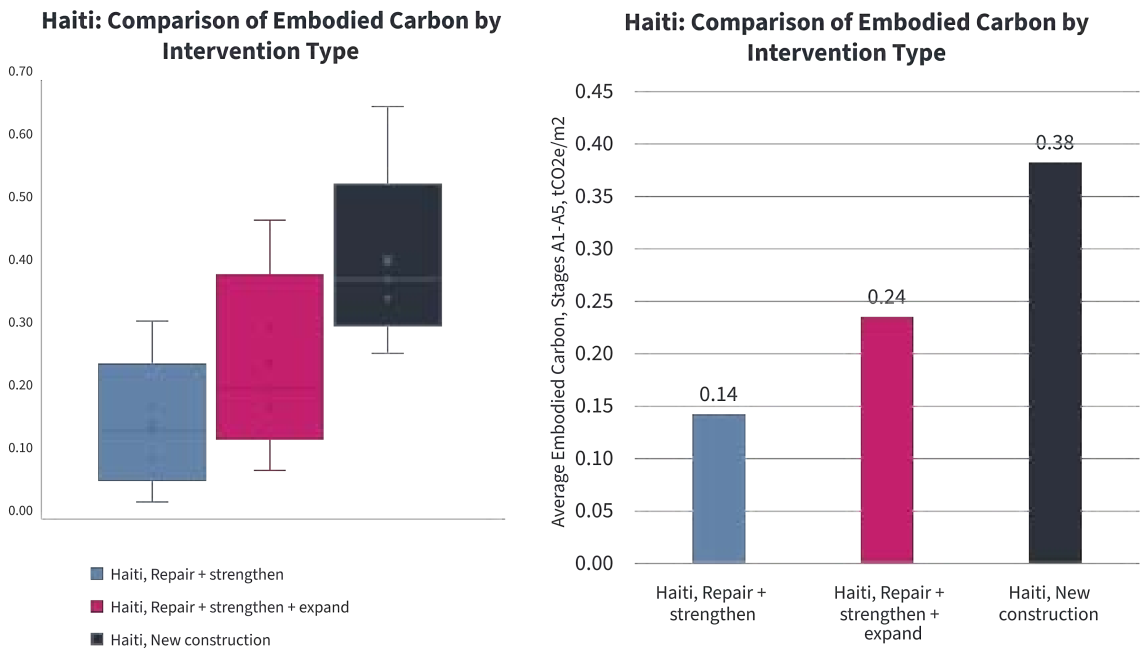
Findings:

Overall, home improvements in Haiti save 59 percent of the emissions of equivalent new construction. On average, post-disaster repair and improvement of existing homes in Haiti saves 20 metric tons of carbon dioxide per house (0.26 tons per square meter).

Emissions savings are slightly lower for Haiti compared to the global average for programs without expansion, largely due to the considerable extent of post-earthquake repairs that were required. For interventions without expansion, the savings in Haiti were 65% of equivalent new construction - slightly lower than the global average savings of 68%. Similarly for interventions with expansion, the savings were 42% and 47% for Haiti and the global average respectively. This is predominantly due to the severity of the earthquake damage and the extent of repairs that were required to the houses. A secondary factor is that Haiti relies heavily on imports for cement, steel reinforcement, timber, and roof sheets, which increases the emissions from transportation.

The biggest emissions savings in Haiti were for houses with repair and strengthening interventions, but house interventions that included vertical expansion also had significant emissions savings. The Haiti program provides an interesting post-disaster context comparison of the impact of vertical expansion on total embodied carbon. All houses had extensive damage repair and structural strengthening interventions, and only some houses also had vertical expansion. While the houses without vertical expansion saved, on average, 71 percent of the emissions of equivalent new construction, the houses with vertical expansion still had average savings of 42 percent of equivalent new construction.

Figure 15: Average Embodied Carbon by Intervention Type in Haiti



5.3 Combining Climate Mitigation with Climate Adaptation in Honduras

Location: *Sula Valley, Honduras*
Context: *Post-disaster (2020 Hurricanes Eta and Iota)*
Number of houses analyzed: *5 retrofit, 1 new construction*
Hazards: *Earthquake, flood, wind*
Building type: *1 story, concrete block masonry, lightweight roof*
Intervention scope: *Repair, retrofit, and vertical expansion to add a partial second story*
Performance level: *Life safety (seismic)*

Program details:

Build Change began working in Honduras after Category 4 Hurricanes Eta and Iota hit the country in quick succession in November 2020. In partnership with the Honduran Red Cross, we began working with homeowners in the Sula Valley, an area in the north west characterized by low-lying, alluvial plains prone to regular flooding. Expected damage in the area is anticipated to increase in the next decades due to economic and population growth, and climate change.[20]

The home improvement program offers homeowners technical and financial resources to repair the damage caused by the strong winds and flood water, while simultaneously strengthening their home against future events. Integral to this is the addition of a resilient partial second story, which will provide shelter and protection during hurricanes and a safe place for families to live while waiting for flood water to subside. Technically, this means providing additional reinforcement to the first-floor masonry walls, converting the existing lightweight roofs to reinforced concrete slabs, and building the partial second story as new construction. It also means providing systems for rainwater harvesting and solar panels for energy independence.

The Sula Valley is considered a rural, agricultural area, although population density is still relatively high. Houses are typically single-story, detached units built from concrete masonry blocks and lightweight roofs.

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[20] UNU-EHS & Frankfurt School of Finance & Management (2021). *Urban Flood Risk in San Pedro Sula – Honduras: Executive Summary.* Bonn/Frankfurt: United Nations University / Frankfurt School of Finance & Management GmbH. 16pp.

Before (left) and after (right) Build Change and Honduran Red Cross technical and financial support for retrofit and expansion of Irma Mercedes Mardiaga's home

Findings:

Climate adaptation programs can also reduce emissions to mitigate the effects of climate change. The Honduras program was designed entirely for climate adaptation. However, the program's reuse and improvement of existing houses has considerable emissions savings when compared with the only viable alternative—relocation and construction of new homes for the affected population. Each improved house saves, on average, 9.5 metric tons of carbon dioxide or 48 percent of the emissions of equivalent new construction.

Figure 16: Emissions Savings with Post-Disaster Programs in Honduras

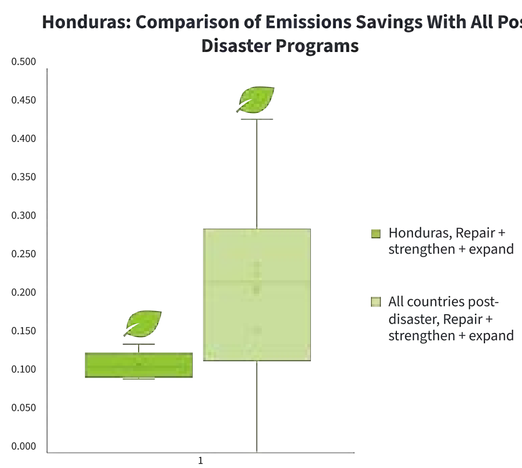
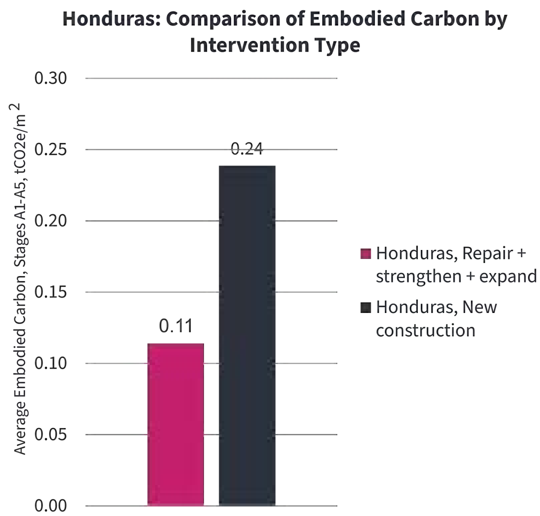


Figure 17: Embodied Carbon by Intervention Type in Honduras



The emissions savings for repair, strengthening, and expansion of existing homes in Honduras are slightly below average compared to comparable global programs. The savings from the Honduras program interventions are on average 53 percent lower than all post-disaster programs with strengthening and vertical expansion. This is thought to be due to two reasons. First, because none of the existing houses have slab roofs—all have lightweight roofs that must be converted to slabs to support expansion. This considerably raises emissions because the steel and cement in reinforced concrete have very high associated emissions, and the slabs themselves are steel deck slabs. Secondly, the finishes on these homes were completed to a higher degree than other vertical expansion programs.

5.4 Nepal: An Efficient Retrofit Approach Can Meet Performance Objectives While Reducing Emissions

Location: *Central and western Nepal*
Context: *Post-disaster (2015 Gorkha earthquakes)*
Number of houses analyzed: *91 retrofit, 1 new construction*
Hazards: *Earthquake*
Building type: *1 or 2 story plus attic, stone with mud mortar or timber frame, lightweight roof*
Intervention scope: *Repair and retrofit*
Performance level: *Life safety*

Program details:

In April and May 2015, Nepal was hit by two consecutive earthquakes, during which more than one million houses collapsed or incurred damages, mostly in rural and hard-to-reach areas of the Himalayan region. A comprehensive survey conducted by the Central Bureau of Statistics after the earthquakes found that only 29 percent of affected homes needed to be reconstructed, and the remaining 71 percent needed to be retrofitted.

The government announced a homeowner-driven reconstruction program, with two subsidy options available to homeowners, depending on the assessed damage level of their house: NPR 100,000 (USD 900) for repair and retrofitting, and NRP 300,000 (USD 2,700) for full construction of a new house. In response, Build Change developed one type design and adapted two government-approved designs for retrofitting: one for stone masonry and mud mortar houses, and one for timber houses. These designs were officially approved by the government in 2017, and subsequently Build Change led and participated in a diverse range of programs focused on scaling home repair and retrofitting in the country.

Throughout the earthquake-affected region, the materials and construction methods used for existing houses are very similar. Houses are typically two stories high, with an additional half story attic space. The walls are thick, unreinforced stone masonry with mud-based mortar. The inter-story floors are timber, and the pitched gable roof is framed with timber and covered with metal sheets or ceramic tiles.

Caption: Stone masonry houses are similar in size and configuration and the most common typology in rural Nepal

Caption: A typical stone masonry in mud mortar house in Eklephat village in Nepal before (left) and after (center) being retrofitted. (Right) 3D structural model of a typical stone masonry house in rural Nepal.

The houses analyzed for this study were retrofitted as part of the National Reconstruction Authority's national reconstruction program. The equivalent new construction baseline is taken from the government's approved standard design catalogs for resilient new construction of stone houses with cement mortar.

Findings:

Overall, home improvements in Nepal save 70 percent of the emissions of equivalent new construction. On average, improving existing homes in Nepal for earthquake damage repair and strengthening saves 15 metric tons of carbon dioxide per house (0.2 tons per square meter).

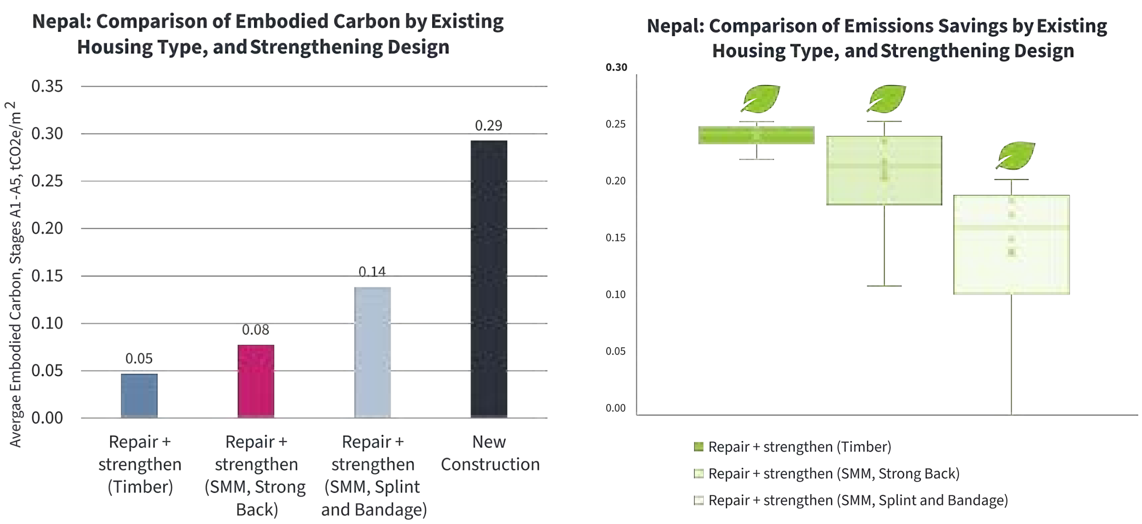
The improvement program in Nepal demonstrates the impact of existing building typology on embodied carbon emissions. On average, strengthening a timber house had lower embodied carbon than a masonry home.

Housing improvement programs have many more constraints than new construction. One key constraint is that the materials of the existing building often dictate what materials can be used for the strengthening design. For example, an unreinforced masonry building typically cannot be strengthened using only timber and instead reinforced concrete is usually required.

The topography of Nepal and remoteness of many communities affected by the earthquake added another layer of constraints. In some cases, access to construction materials was difficult, and with limited financial subsidies available to homeowners, each material had to be transported from the market centers, which were sometimes located at a distance from the homes. But from an embodied carbon perspective, these constraints were all benefits as they forced the retrofit design to minimize imported, high carbon materials and maximize local, natural materials such as stone and mud.

The Nepal program also demonstrates how the strengthening design can impact the emission savings. For stone masonry houses with mud mortar, two different strengthening techniques were used, referred to as "strong back" and "splint and bandage." On average, the emissions savings from adopting the strong back design approach are almost 40 percent higher than for the splint and bandage approach. Both approaches are effective at reducing the vulnerability of the house to earthquakes, with comparable financial costs.[21]

Figure 18: Embodied Carbon by Existing Housing Type and Strengthening Design in Nepal



SMM = stone with mud mortar

[21] Giordano, Nicola, et al. "Financial assessment of incremental seismic retrofitting of Nepali stone-masonry buildings." *International Journal of Disaster Risk Reduction* 60, (2021). https://doi.org/10.1016/j.ijdrr.2021.102297

5.5 Why Improving an Existing House *Before* a Disaster in the Philippines Saves More Embodied Carbon Emissions Than Waiting Until After the Disaster

Location: *Luzon and Visayas, Philippines*
Context: *Post-disaster, prevention*
Number of houses analyzed: *48 retrofit, 2 new construction*
Hazards: *Wind, earthquake*
Building type: *1 story, concrete block masonry with lightweight or reinforced concrete slab roof*
Intervention scope: *Retrofit, some with vertical expansion to add a second story*
Performance level(s): *Life safety, risk reduction*

Program details:

Build Change has been supporting post-disaster reconstruction in the Philippines following Typhoon Haiyan (known locally as Yolanda) in 2013. However, since 2016 the majority of its programs have been focused on disaster prevention. In contrast to Build Change's other global programs, the funding model for home improvements in the Philippines predominantly uses private sector finance—loans taken by homeowners from micro-finance institutions (MFIs)—in addition to philanthropic giving, rather than public funding.

Build Change currently has partnerships with four MFIs to offer home strengthening loans, which provide homeowners with the necessary technical as well as financial support to strengthen their home against hurricanes and earthquakes. Most of the houses analyzed for this study were either part of the loan pilot program or commercial customers of the loan.

The houses are typically single-story, with concrete block masonry walls—either unreinforced, or only partially reinforced and/or confined. The improvement interventions are divided into packages that homeowners can implement incrementally, allowing them to split costs over multiple loans to avoid long loan terms and high interest payments.

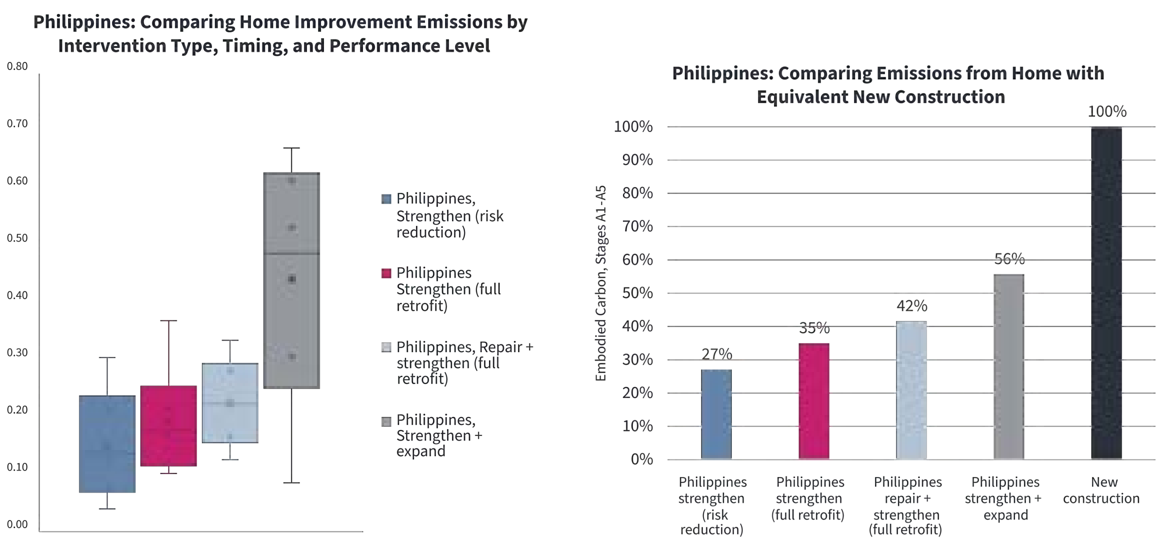
Caption: Before and after: Homeowner Josefina Hagosojos's house was part of a home improvement intervention in The Philippines

Findings:

Overall, home improvement programs in the Philippines save 60 percent of the emissions of equivalent new construction. On average, improving existing homes saves 14 metric tons of carbon dioxide per house (0.35 tons per square meter).

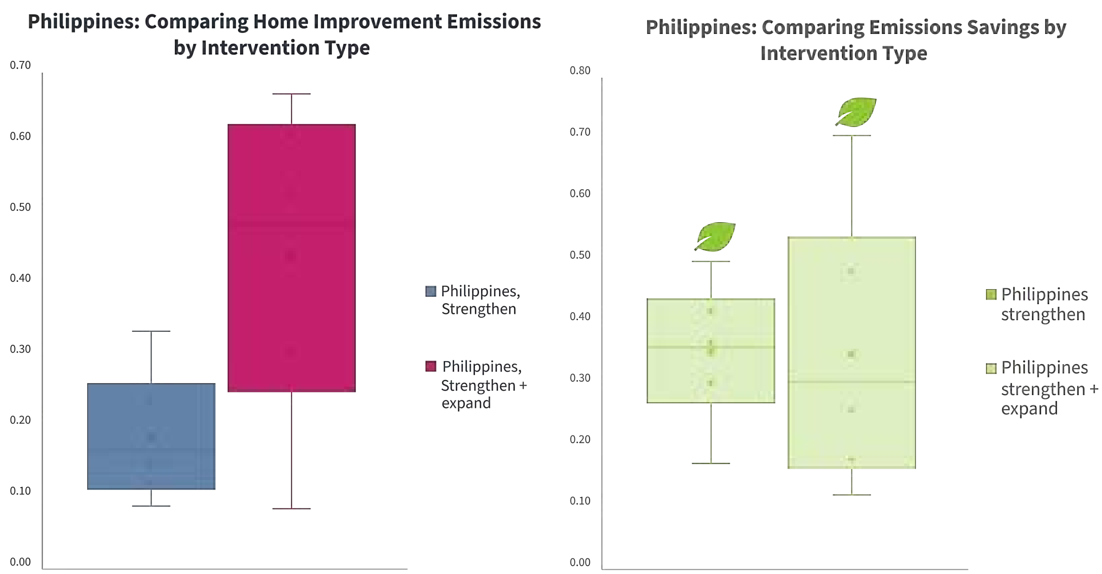
Emissions are lower for risk reduction and preventative strengthening projects, and highest when projects are carried out post-disaster and include vertical expansion. The variety of project types in the Philippines program offers an interesting comparison of the impact on carbon emissions. As expected, the intervention type with the lowest emissions are projects that are carried out preventatively and target a risk reduction performance level. Strengthening to life safety performance level increases emissions from 27 percent to 35 percent of equivalent new construction when carried out preventatively before a disaster, and to 42 percent of equivalent new construction when performed post-disaster.

Figure 19: Home Improvement Interventions with Equivalent New Construction in the Philippines



Although vertical expansion considerably increases the emissions of the intervention, the savings are still comparable to strengthening only interventions. For houses with vertical expansion as well as strengthening, the average emissions are 0.44 tCO_2e/m^2—more than double the emissions of a house with strengthening only (0.19 tCO_2e/m^2). However, when compared to their respective new construction baselines, the average emissions savings from both types of intervention are the same.[22] The opportunity to safely expand their home and earn additional income from retail or rental space is often a major incentive for homeowners to strengthen their homes, particularly in space-constrained areas of metro Manila.

Figure 20: Home Improvement Emissions by Intervention Type in the Philippines



[22] Average emissions savings of homes with strengthening only: 0.35 tCO_2e/m^2; emissions savings of homes with strengthening and vertical expansion: 0.35 tCO_2e/m^2.

5.6 Sint Maarten: The Impact of Design Performance Level on Emissions Savings

Location: *Sint Maarten*
Context: *Post-disaster (2017 Hurricane Irma)*
Number of houses analyzed: *37 retrofit, 2 new construction*
Hazards: *Earthquake, wind*
Building type: *1-3 story, concrete block masonry with lightweight or reinforced concrete slab roof*
Intervention scope: *Repair and retrofit, some with vertical expansion to add a second story*
Performance level(s): *Life safety, risk reduction*

Program Details:

Housing in the Caribbean island of Sint Maarten was severely affected by Category 5 Hurricane Irma in September 2017. Build Change worked with the country’s National Recovery Program Bureau (NRPB) to provide technical assistance to their housing recovery program.

Given the limited funding available and the large number of damaged houses, the NRPB favored a program which would support as many of the country’s homeowners with the highest socio-economic vulnerability as possible. From an engineering perspective, most of the houses selected to receive grant funding for repairs had masonry walls that were well built and had little hurricane damage, but their roofs lacked sufficient capacity, and had moderate to severe damage.

Build Change worked with the NRPB to design a housing repair and improvement program that would have two principal levels of intervention depending on the existing condition of the house:

- **Life safety:** For small houses that did not meet minimum requirements for earthquakes and wind, we implemented a full retrofit that would bring the whole building—walls and roof—up to a code-compliant, life safety performance level. Life safety means that for wind speeds up to and including the design level, the building may experience damage, but not to such an extent that there will be loss of life.
- **Risk reduction:** For larger houses that had not been severely damaged, we implemented a risk reduction intervention. Strengthening for risk reduction does not bring the whole building up to minimum code requirements for life safety, but it brings the most critical components up to (or close to) a life safety performance level. A risk reduction intervention still improves the overall resistance of the building to hurricanes and earthquakes. For the houses in Sint Maarten, this

meant that we mostly intervened in the roofs by providing additional capacity to the framing elements and to the connections, as well as repairing or replacing the covering.

Improvements for habitability were included regardless of the intervention level, and included new windows and doors, and replaced electrical wiring and panel boxes. This has not been calculated in the embodied carbon.

Houses in Sint Maarten are typically one to three stories high and comprise masonry walls (partially reinforced, often with reinforced concrete columns at wall intersections) and a ring beam above all exterior walls. Roofs are typically pitched with timber framing and clad with galvanized metal sheets, or solid reinforced concrete slabs.

Findings:

Overall, home improvements in Sint Maarten saved 76 percent of the emissions of equivalent new construction. On average, strengthening existing homes in Sint Maarten as part of the NRPB's program saved 40 metric tons of carbon dioxide per house (0.2 tons per square meter).

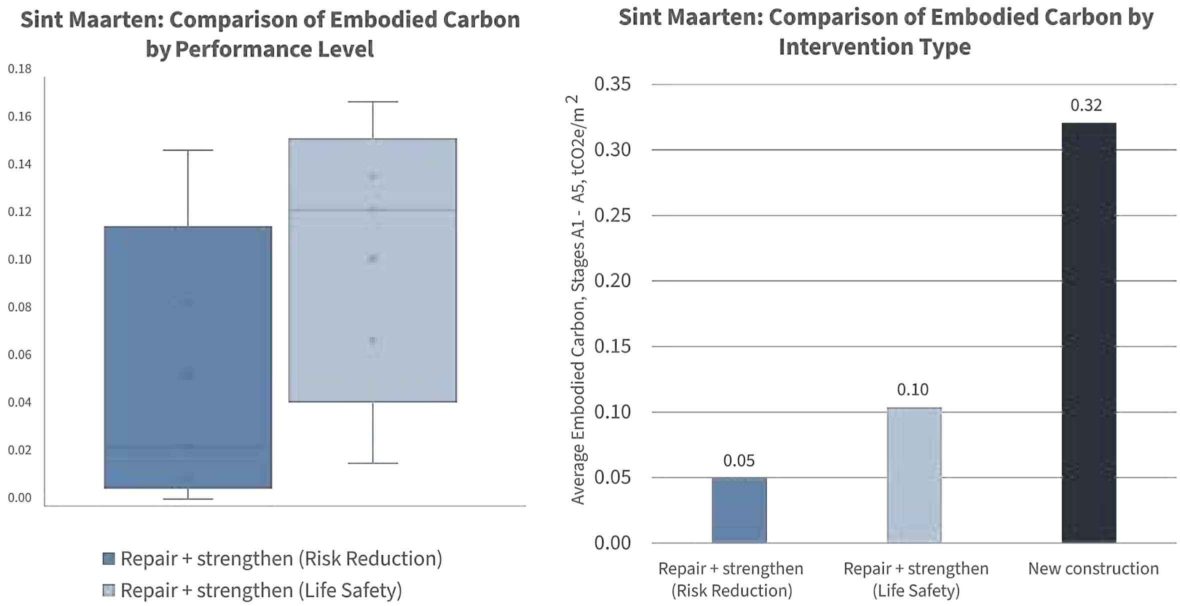
The savings in Sint Maarten are some of the highest of all design groups due to the higher quality of the existing houses, the cultural acceptance and prevalence of lightweight roofs, and the design performance level. The design and construction quality of the foundations and walls of existing housing in Sint Maarten meant that there was less damage to these elements that required repair, nor was there substantial need for strengthening. In general, most of the damage was to the roofs.

The design performance level can have a significant impact on embodied carbon emissions. The two intervention levels in the Sint Maarten program provide an interesting comparison of the impact performance level can have on the emissions of a housing retrofit program. Comparing the sample of 37 repaired and strengthened houses to equivalent new construction, the savings by strengthening to a risk reduction and life safety performance levels were 85 percent and 69 percent, respectively.

In addition to the carbon savings, risk reduction interventions are typically cheaper than full life safety interventions. Risk reduction interventions are also quicker and less invasive, which means homeowners are displaced from their homes for shortened periods of time (if at all) and have less superficial redecorating to do after the structural work is completed.

In contexts where the design and construction quality of housing is already reasonable, designing housing interventions for risk reduction rather than life safety performance can be an effective way to balance the financial and environmental cost of interventions with the need to minimize damages in future disasters.

Figure 21: Embodied Carbon by Performance Level and Intervention Type in Sint Maarten



6.0 Detailed Approach and Methodology

6.1 Framing the Approach

Two key decisions were made that frame our approach to quantifying the emissions associated with our housing intervention programs. Firstly, the home improvements are compared to a new construction baseline. For each house, the emissions associated with the intervention are calculated relative to construction of a new house in the same location with an equivalent level of resilience.

Secondly, we have only considered the upfront embodied carbon emissions, those from lifecycle stages A1-A5 (material extraction, processing, and construction) in Figure 4. The emissions associated with building operations during habitation, such as energy use from cooking, heating, cooling, and lighting, are not considered, nor are the emissions associated with building end of life.

The details and reasoning behind this approach are provided in the following two subsections 6.1.1 and 6.1.2

6.1.1 Emissions Are Compared to a New Construction Baseline

For each house, the emissions associated with the intervention are calculated relative to construction of a new house in the same location with an equivalent level of resilience.

In most cases, new construction is the most likely alternative to retrofit. Build Change's housing improvement programs typically fall into one of two contexts: post-disaster, focused on housing reconstruction; and prevention, where housing in disaster-prone areas is strengthened before a disaster occurs. In both scenarios, new construction is the most common solution to the problem of inadequate housing.

Post-disaster, decision-makers such as governments, the private sector, and aid agencies have typically tended to demolish or abandon damaged housing and build new homes. "Doing nothing" is not an option as the level of damage means houses are either unsafe or (at best) uncomfortable for habitation. Often houses are damaged because of deficiencies in their original design, so repairing the damage and restoring the house to its pre-disaster condition is not appropriate either; the house will be damaged again in future disasters.

In prevention contexts, apathy toward the risk often leads to a "do nothing" approach. However, the potential consequences of high human and economic losses mean that, in reality, "do nothing" is not an option. When faced with the choice of how to act, an absence of technical guidance and regulation on improving existing buildings combined with the greater publicity opportunities offered by new, large-scale developments often leads developers, builders, homeowners, and governments to opt for new construction.

A relative approach standardizes the results and allows compilation and comparison on a global scale. Build Change has implemented housing projects and programs in 26 countries across four continents. Housing design and construction varies considerably around the world, and, correspondingly, so do our retrofit designs. By always comparing our retrofit intervention against resilient new construction with a similar performance level, it allows us to compile the results into a single, international database and compare the impact of different contexts and program features.

Considering the results relative to a baseline addresses many of the challenges of uncertain or absent data. Carbon emissions accounting in construction is a relatively new activity that is largely concentrated in Europe and North America. In the countries and regions in which Build Change works, very few materials producers issue environmental product declarations (EPDs) or self-declarations that contain the data required for precise calculation of the embodied carbon. Globally, no published national or international data for structural housing retrofit could be found to use as a benchmark. Using the same data to calculate the emissions associated with new construction as for retrofit for the same location cancels out inaccuracies when we measure the relative difference between the two interventions.

6.1.2 Only the Upfront Carbon Emissions Are Considered

The analysis considers only the embodied carbon emissions associated with lifecycle stage A, the emissions from stages B, C and D are not considered.

The primary reason for only considering stage A emissions is that our focus is on quantifying the difference between improving an existing home and building new. We are assuming that, in most scenarios studied here, the emissions from stages B, C and D will be the same or very similar for a new house as for a retrofitted house, so when the two are compared, stage B, C and D emissions will cancel out.

From experience, we know that homeowners do not significantly alter their energy supply or usage following a retrofit intervention, so there is little difference to the stage B operational emissions. Even in cases where the intervention includes expansion, for example by adding a second story, the change in operational carbon is negligible compared to embodied carbon.

Similarly, we know that building emissions during end of life and beyond (stages C and D) are very similar for retrofitted and equivalent new houses. Although the *cause* of end of life may result in different emissions[23], the emissions associated with end of life will still be the same regardless of whether the house was an improved existing house or a new construction.

Secondary reasons for only considering stage A emissions are as follows:

- **Embodied carbon emissions due to materials and construction (stages A1–A5) account for the majority of a building's emissions over its life cycle.** Estimates for the UK indicate that stages A1-A5 account for 55 percent of total emissions (see Figure 4). This proportion would be even higher in the countries where Build Change operates, where operational energy use and refurbishment levels are much lower than the UK.
- **Recent technological advancements and regulations have significantly reduced operational carbon as a proportion of whole life carbon.** The global construction industry has significantly decreased operational carbon in the built environment in recent years. Advancements in reducing embodied carbon have been slower, and as a result embodied carbon is increasingly accounting for a higher proportion of whole building life cycle emissions.[24]

[23] For example, the amount of emissions from an end of life caused by a fire is different from the end of life caused by an earthquake, or a hurricane. Houses damaged beyond repair and retrofit following an earthquake often still have salvageable elements, such as window and door frames, that can be reused or recycled. Following a fire, there is no such option to reuse or recycle materials.
[24] Buildings Performance Institute Europe. *Whole-life Carbon: Challenges and solutions for highly efficient and climate-neutral buildings* (2021).

- **There is limited data available** for building emissions during stages B, C, and D, as Build Change is not (currently) tracking how buildings are used beyond construction completion. For example, we do not know if homeowners add additional electrical appliances, or install solar panels. Nor do we know whether they choose to recycle materials at building end of life, or whether everything is sent to landfill.
- **Houses in Build Change programs have very low in-use consumption.** Typically, the houses in our programs have low operational emissions—they have few electrical appliances, and they usually do not have air-conditioning or heating. Simple estimates indicate that operational emissions would account for a very low percentage of total life emissions.

6.2 Calculation Approach

For the reasons described in Section 6.1, the analysis considers only the emissions from lifecycle stages A1-A5, not stages B, C or D.

The analysis is based predominantly on guidance from the UK Institution of Structural Engineers' "How to Calculate Embodied Carbon", 2nd edition, published in 2022. This document is aligned with British Standards for sustainable construction: BS EN 15978,[25] BS EN 15804.[26] The following sections detail how the guidance was applied to calculations of embodied carbon savings for Build Change's as-built housing dataset.

6.2.1 Stages A1–3, Production and Transport of Raw Material:

For stages A1–A3 (raw material supply, transport, and manufacturing), the embodied carbon of each material was calculated as follows:

$$\textit{Embodied Carbon}_{A1\text{-}A3}\,(kg{\cdot}CO_2e) = \textit{Material Quantity}\,(kg) \bullet \textit{Embodied Carbon Factor}_{A1\text{-}A3}\,(kg{\cdot}CO_2e/kg)$$

Material quantities were taken from the construction bill of quantities (only built projects have been considered).

The embodied carbon factors were selected from a range of sources following significant research and consideration. As much as possible, we have used material- and producer-specific EPDs or self-declarations. However, the majority of the materials suppliers used by homeowners that are involved with Build Change programs were unable to supply EPDs when contacted. In the countries where Build Change works, there is not yet sufficient demand nor regulation requiring materials producers or importers to provide this information to customers.

Where EPDs are not available, we have used two databases as our primary data source:

- the Inventory of Carbon and Energy database V3 (ICE3),[27] and

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https://www.bpie.eu/publication/whole-life-carbon-challenges-and-solutions-for-highly-efficient-and-climate-neutral-buildings/

[25] British Standards Institution. BSEN15978:2011: Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method. London: BSI, 2011.

[26] British Standards Institution. BSEN15804:2012+A2:2019: Sustainability of construction works. Environmental product declarations. Core rules for the product category of construction products. London: BSI, 2021.

[27] The ICE database is a meta-database, based on data from an extensive literature review led by Dr Craig Jones (circular ecology) and Professor Geoffrey Hammond (University of Bath). Eighty-eight percent of the data reviewed

- the Embodied Carbon in Construction Calculator (EC3) database.[28]

Both databases are among the most well regarded and complete of all EPD and embodied carbon factor databases currently available internationally.

6.2.2 Stage A4, Transport to the Construction Site:

Stage A4 considers the transport of materials or products from the factory gate to the construction site, and the transport of construction equipment (cranes, scaffolding, etc.) to and from the site. Similar to stages A1-A3, the embodied carbon for stage A4 is calculated for each material as follows:

$$\text{Embodied Carbon}_{A4}\ (kg \cdot CO_2e) = \text{Material Quantity}\ (kg) \bullet \text{Embodied Carbon Factor}_{A4}\ (kg \cdot CO_2e/kg)$$

Where the Embodied Carbon Factor for stage A4 is calculated as follows:

$$\text{Embodied Carbon Factor}_{A4} = \sum_{mode} (TD_{mode} \bullet TEF_{mode})$$

TD_{mode} is the transport distance for each transport mode considered and TEF_{mode} is the Transport Emission Factor (TEF) for each transport mode considered.

The mode of transport is known for all Build Change programs and the distance traveled is estimated to the nearest 100 kilometers based on known origin and final destinations. The TEF is based on UK transportation emissions as follows:

Mode of transport (km)	Road	Sea	Freight Air	Rail
Transport Emissions Factor (TEF), kgCO2e/kg	0.1065	0.01614	0.59943	0.02556

Source: IStructE How to Calculate Embodied Carbon

6.2.3 Stage A5, Construction:

The embodied carbon associated with the construction installation process (stage A5) is calculated based on two key sources of emissions, as follows:

$$\text{Embodied Carbon}_{A5}\ (kg \cdot CO_2e) = \text{Embodied Carbon}_{A5w}\ (kg \cdot CO_2e) + \text{Embodied Carbon}_{A5a}\ (kg \cdot CO_2e)$$

- **A5w: The emissions associated with the volume of each material that is wasted on site.** The total weight of each material is multiplied by a waste rate factor. The waste rate factors that have been adopted for all case studies are those recommended in the IStructE's Structural Carbon Tool and are presented in the table below.

is EPDs in accordance with EN 15804 (the majority of the remainder are to ISO 14067, ISO 14044, or claim no standardized method).

[28] The EC3 tool contains a freely accessible database of EPDs from materials producers, predominantly in North America but also globally. Embodied carbon factors are grouped by material type, the range and average of values can be easily viewed, and values can also be viewed by region. EC3 was incubated at the Carbon Leadership Forum with input from nearly 50 industry partners. It is now owned and managed by Building Transparency.

Material/Product	WR (waste rate)
Concrete in situ	5.0%
Mortar	5.0%
Screed	5.0%
Steel reinforcement	5.0%
Steel frame (beams, columns, braces)	1.0%
Concrete blocks	20.0%
Brick	20.0%
Stone	10.0%
Timber frames (beams, columns, braces)	1.0%
Timber floors (joists, board)	10.0%
Timber formwork	10.0%
Glass	5.0%
Plasterboard (for boarding)	22.5%

- **A5a: Emissions due to general construction activities**, for example the energy use from machinery and temporary site offices. International guidance to calculate emissions from construction activities recommends using a construction activities emission factor that is multiplied by the project cost. This methodology, however, has been developed for regions where the project cost is orders of magnitude higher than the housing retrofits that Build Change implements. For this reason, it was not felt to be appropriate. Instead, we have developed an alternate methodology, more appropriate for the regions in which we work. We have defined and calculated the emissions associated with three levels of construction site activities, as shown below. For each program or project analyzed, the most appropriate of the three levels has been adopted to account for emissions associated with the construction process.

Level of Activity	Description	Applicable Countries	Emissions (kgCO2e per site)
1 – Very low	No or almost no energy use on site. Concrete mixed by hand with shovels; no use of power tools, cranes, or generators. All works, including concrete mixing, carried out by hand.	Haiti	50
2 – Low	Low energy consumption on site. Limited use of a diesel generator to power a site mixer for concrete production, lights, and some power tools. No use of cranes, excavators, or other heavy machinery.	Honduras, Nepal, Philippines	200
3 – Average	Average energy consumption on site. Regular use of a diesel generator on site to	Colombia, Sint Maarten	550

	power lights and tools. Ready mix concrete delivered to site. Very limited, if any, use of cranes, excavators, or other heavy machinery.		

6.3 Calculation Tools

For most programs, we calculated the embodied carbon emissions associated with stages A1–5 using simple spreadsheets. However, with the support of Autodesk and the Autodesk Foundation, we developed digital tools to semi-automate embodied carbon calculations in Revit. These tools will be integrated into our Building Information Modelling workflow for all future projects in Revit. They will greatly facilitate the collection of emissions data and provide real-time information to our engineers about the environmental impact of design decisions.

Caption: Revit was used to semi-automate embodied carbon calculations

6.4 Calculation Limitations

It is important to note the following limitations with this analysis:

- **The probability of damage in preventative contexts is not considered.** In both post-disaster and prevention contexts, the emissions savings from a home improvement intervention were compared to new construction as a baseline. Ideally, the probability of future damage occurring would also be factored into the comparison. However, the multi-hazard nature of the project locations puts this consideration beyond the scope of this study.
- **The majority of the material emissions factors were obtained from global or regional meta databases and as a result are not specific to the exact materials and supplier used.** Unfortunately, this was not a choice. Carbon accounting is not yet commonplace in Build Change's program locations, and none of the suppliers contacted were able to provide data. Depending on the material, there can be a very large range in the magnitude of the emissions factor and large differences can even exist between different providers in the same region. This is especially true for timber, corrugated galvanized iron (CGI), and galvanized profiles, for which global average data from the ICE3 database was used. The impact of using the global average data for these materials was deemed acceptably low as these materials are not significant contributors to the overall home improvement emissions (see Figure 11).
- **Historical emissions data was not used.** The production processes of materials change over time —hopefully for the better—and as a result the materials emissions factor may also change.

However, historical data was largely not available for the materials and site locations of Build Change projects. For example, many Haiti home retrofits were completed in 2013, but material data from 2022 was used. Given that average values were used, this is not expected to have a significant effect on the results.