A VULNERABILITY ASSESSMENT TOOL FOR RESIDENTIAL STRUCTURES AND EXTREME WIND EVENTS

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ABSTRACT

Studies of hurricane damage to residential buildings confirm that the risk of wind and/or water damage related losses can be mitigated via retrofit solutions. However, adoption of appropriate retrofits by homeowners has been limited despite its obvious benefits. For several reasons, including high cost of retrofitting, the practical difficulty of implementing upgrades, and other homeowner priorities, the level of structural retrofits remain low. This paper proposes a performance-based design approach to retrofitting, targeted for residential homeowners (and their construction team) to advise on incremental retrofits that ultimately result in desired performance targets for wind-resistant houses. To specifically engage the homeowner, a user-friendly smartphone application is developed that evaluates the wind resistance and vulnerability of existing homes. The app provides each homeowner an individualized vulnerability assessment, while engaging and educating them on the effects of structural systems and building characteristics on damage and on the options for retrofits and costs associated with the work. The vulnerability assessment is determined using a database of fragility curves, developed originally for the FEMA's HAZUS-MH program, and adapted for this use. The analysis yields the top three recommended retrofits for each house as-is, and its expected hurricane-induced economic losses compared against the predicted loss if all the retrofits were conducted. Beta trials of the mobile app will be conducted in at-risk coastal communities in Florida, USA. The authors suggest that direct engagement of homeowners in identifying wind mitigation techniques and solutions may yield more positive outcomes than traditional communication approach and it may eventually increase the number of building retrofits.

KEYWORDS

Vulnerability, performance-based design, smartphone, risk communication, resilientresidence, resre.

INTRODUCTION

The use of performance-based design (PBD) is recognized in the engineering community as the most rational means of assessing and reducing the risks of engineered buildings subject to natural disasters (Ciampoli et al. 2011). PBD requires the designers to go beyond code prescriptions and accurately predict how a structure will respond to its environment, often during extreme events. To make these predictions often requires sophisticated structural analysis using state-of-the-art computer software, and sometimes requires laboratory testing. The objective of PBD is to assess the adequacy of a structural system based on a set of decision variables (DV). Each DV is typically a (quantitative) measure of the structural performance that can be defined in terms of interest to the stakeholder. In the case of cyclone-resistant housing construction, building codes have historically focused on life safety. In the wake of extreme economic losses following cyclones over the last 25 years, wind engineering has become increasingly focused on reducing insured loss to structures. Thus vulnerability to wind and water-ingress damages has become an appreciable DV for residential structures. Considering the bulk of housing stock constructed prior to more recent enhancements of building code provisions, a mechanism is need to assess the vulnerability of existing housing (which is specific to each structure) on a large scale. ResilientResidence™ aims to facilitate this mechanism in creating a platform by which homeowners can self-assess vulnerability based on the utilization of research-based vulnerability models (e.g., HAZUS).

BACKGROUND

The damage caused by hurricanes to coastal infrastructure in the U.S. averages about $5.3 billion per year (PCS 2014). In Florida specifically, the inflation-adjusted thirty-year catastrophe losses (including all hazards) between 1983 and 2013 were $66.8 billion, 14% of the total catastrophe losses for the entire United States over the same period (PCS 2014). Within this 30-year period, Florida suffered from the Category 5 Hurricane Andrew in 1992 that destroyed over 25,000 homes and damaged 100,000 others. This single event caused $23 billion (in 2013 dollars) in insured losses, over a third of the 30-year catastrophe losses in Florida. That disaster prompted major changes in how we build, including the adoption of wind-resistance provisions in the 2001 Florida Building Code that addressed many of the structural vulnerabilities exposed by Hurricane Andrew. The effectiveness of this code was put to the test in 2004, when four hurricanes impacted the state of Florida: Charley in the southwest, Ivan in the panhandle, and Frances and Jeanne on the East coast. Statistical analysis of the post-storm damage assessments showed that homes built to the 2001 building code performed significantly better than pre-2001 homes in nearly every area surveyed (ARA 2008; Gurley and Masters 2011). However, while the current building code assures that new homes are safer and less likely to experience severe damage, homes built prior to the code remain vulnerable to future damage. Further, analysis of public county records from the Florida Geographic Data Library (FGDL 2015) indicate that 80% of Florida’s 5 million detached, single family homes were built before 2002, as shown by county in Figure 1.

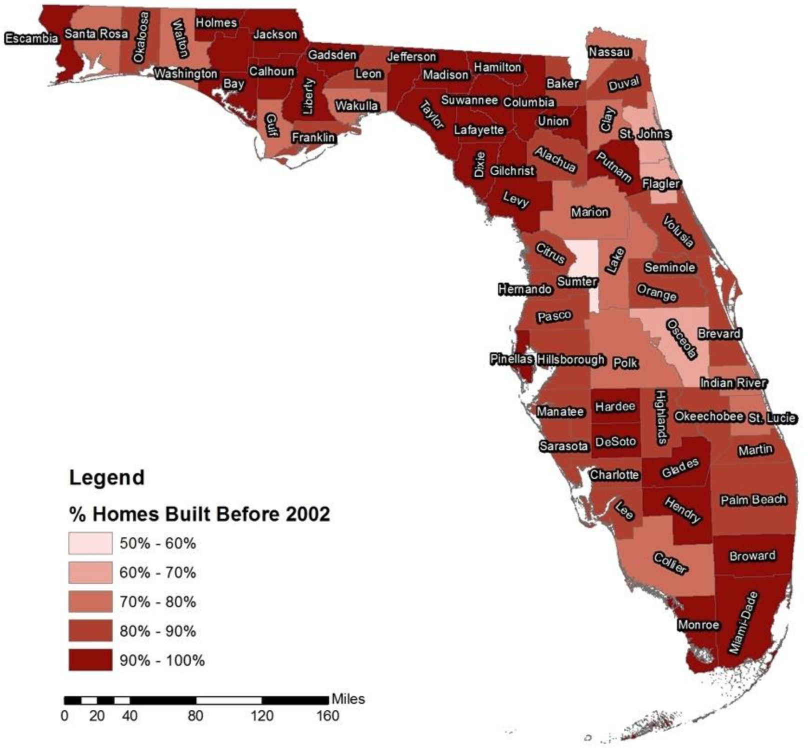


Figure 1. Percentages of homes built prior to 2002 in each Florida county. Data obtained from public county records in Florida (FGDL 2015).

Despite significant advances in knowledge and more efforts to implement stringent wind-resistant building codes in Florida over the past few decades, the majority of houses in Florida may still suffer disproportionately large structural damage from future hurricanes. The existing structural systems in Florida’s homes lack wind-resistant details and adequate structural load paths that prevent brittle failures of the structures, and at less than design level wind speeds. The situation is exacerbated by the 80% proportion of the state’s insured homes, (approximately $2.8 trillion) that are located in coastal (hurricane-prone) regions (Insurance Information Institute 2014). Together these data demonstrate that Florida’s vulnerability to hurricane impacts remains high, despite a strengthened building code ranked second in the US by the Insurance Institute for Business and Home Safety (IBHS 2015) and more than 20 years of better building construction following Hurricane Andrew. Wind engineers have identified a number of cost-effective protection measures that can be retrofitted to existing homes. Despite efforts by state officials, and NGOs to promote mitigation through information and economic incentives, these retrofit techniques have not been widely adopted by Florida homeowners. Unless the implementation of these techniques is substantially increased in older homes, continued storm damage may erode market values of the surviving homes and discourage community investment in rebuilding.

Dissemination of hurricane risk to the general public has occurred on a broad scale, but it has been difficult to engage the homeowner to understand and act on their personal risk (Wood et al. 2012). A population's ability to perceive risk and consequences of events beyond the immediate event is low (Fischer et al. 2015). Studies show that homeowners understandably devote more thought to the immediate effects of natural disasters than the long-term effects and therefore are more concerned with survival actions (e.g. first aid kits, water supply) than mitigation actions (Fischer et al. 2015). However those homeowners are often unaware of the solutions that can mitigate their losses from natural disasters. Historical evidence suggests that experiencing a disaster may be the strongest public motivator to prepare/mitigate for the next event, albeit coming after the event. However, the window for action quickly closes as the memory of experiencing an event declines as time passes. Weinstein (1989) found that the perceptions of safety reemerge and rise back to pre-event levels, typically within a two-year period.

As a result, the general public is disconnected from the hurricane risks and the majority of solutions proposed to mitigate future damage. In general, the public often assumes that insurance will protect against any losses and that the period of recovery will be short and relatively painless. However, hurricane damage deductibles (i.e. excess) are high (from 2- 5% of the value of the home), and insurers have prerogative to reject claims where long-term aging effects and hurricane-related damages are indistinguishable. Many homeowners do not appreciate that post-hurricane reconstruction is more expensive, and generally requires a longer timeline. Further, homeowners seldom consider that hurricane-induced wind and water damage may require temporary housing for weeks or months, resulting in considerable long-term disruptions to their lives.

Hence, the residents of vulnerable homes may possess unrealistically high expectations of personal safety stemming from a lack of exposure to the disparities in construction practices between older and newer Florida homes. Fischer et al. (2015) found that the top two reasons homeowners did not take earthquake mitigation actions was because they had not thought about it or did not believe it necessary for their home. Additionally, an overabundance of information on hazard risk (e.g. news reports, TV Specials) rather than preparedness actions hinders the implementation of mitigation solutions (Wood et al. 2012). In general, two prominent preparedness adoption barriers commonly noted in previous literature are risk perception, and lack of clarity regarding the benefits of preparedness actions (Bourque 2013; Ge et al. 2011; Wood et al. 2012). Both of these barriers can be addressed through a performance-based design approach. As described by van de Lindt (2009), this design approach specifies specific performance objectives and safety goals that a community or building owner desire to achieve, and a probabilistic evaluation of design alternatives against the performance objectives for a given hazard level. This paper describes the framework for a mobile app entitled ResilientResidence™ (ResRe) (www.resilientresidence.com) that provides a personalized wind risk assessment of a user's home, including the expected losses that would occur in a scenario event, using a performance-based design approach.

DEVELOPMENT OF A MOBILE APPLICATION

The concept for the ResRe mobile application was developed in 2013 by a team of engineering doctoral students (Daniel Smith, David Roueche, and Austin Thompson) supervised by Associate professor David Prevatt. Though a number of mediums are available for conveying risk information, the development and near ubiquitous adoption of smartphones in the US (as shown in Figure 2) make it an ideal platform for a decision aid.

Research has established the effectiveness of smartphones as mobile education devices (Song et al. 2012) and has proposed the use of smartphones in disaster communication (Meltzer et al. 2015; Riddell et al. 2011) and as decision support tools in building energy conservation strategies (Leslie 2012).

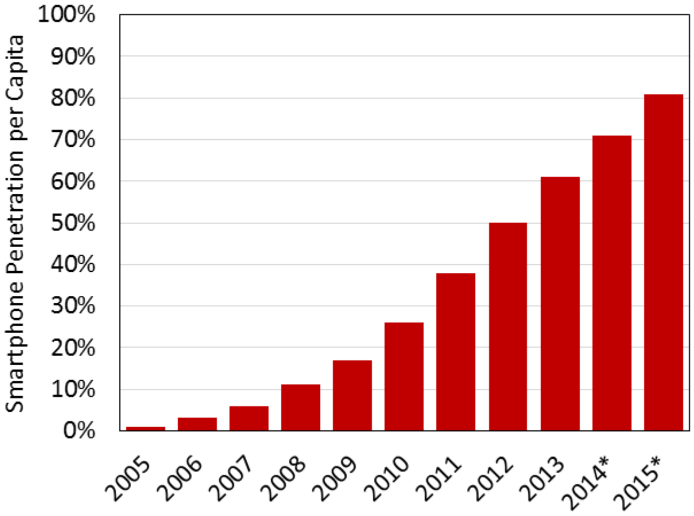


Figure 2: Current and projected(*) smartphone ownership in the United States from 2005 – 2015 (eMarketer 2014)

The personalized risk and vulnerability assessment of ResRe requires an engineering-based loss model to establish the relationship between wind speed and expected monetary losses for a given residential structure type. This is publicly available in the HAZUS-HM hurricane catastrophe model, a peer-reviewed, multi-hazard catastrophe model distributed by Federal Emergency Management Agency (FEMA) (Vickery et al. 2006). A primary component of HAZUS-HM is a library of loss functions that relate hurricane wind speed and expected building losses (normalized to the value of the home) for various building types. The loss functions are extensive, including 1,024 different configurations of residential buildings. When a specific home is defined within ResRe, it is matched to a specific loss function in the HAZUS-HM library. The expected losses for that home are determined for a given wind speed based upon the value of the home. The benefits of retrofitting are then evaluated by comparing the expected losses for the same home configurations with added mitigation features to the expected losses of the original home. The methodology is illustrated by Figure 5. In this example, the difference in building loss ratios of 0.18 for a Category 1 hurricane suggests that for a home valued at $200,000, the retrofitted home would have ~$36,000 less damage than the unretrofitted home.

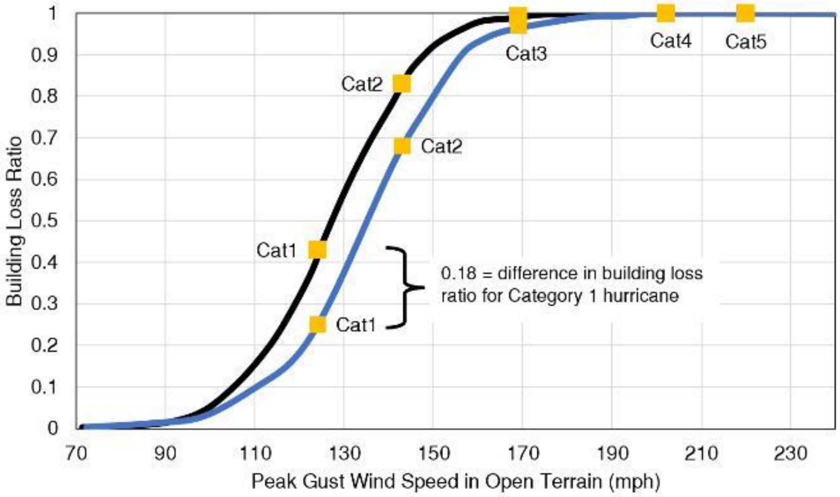


Figure 3. Illustration of building loss functions for a woodframe, one story, gable home without retrofits (black) and retrofitted with hurricane straps and stronger roof sheathing fasteners (blue). Gold-colored squares represent the maximum 3-second gust wind speed associated with Category 1-4 hurricanes and a representative value for a Category 5 hurricane.

It is understood that HAZUS-HM loss functions represent generalized structures and therefore have limited accuracy at house-level resolution. However, these curves can be used to provide a rational basis for comparative analysis between wind-resistant building features. Their use in this application also enables meaningful risk communication to homeowners through dollar figure loss estimations.

PROGRAM LOGIC

The customized analysis of a ResRe user's home is completed by a program coded into the background of the app, behind the guided user interface (GUI). The program completes a vulnerability assessment and retrofit optimization for the user based on the input data collected by the GUI. The data collected from the user includes: [a] building characteristics (e.g., location of the home, year of construction, roof shape, wall material, number of stories, appraised home value) and [b] current protection levels for building components (e.g., roof cladding, roof to wall connections, wind protection, roller door rating, roof framing) that affect the vulnerability of a residential structure. The protection levels for each component (e.g. strong, medium, weak) are determined by the user within the GUI through a questionnaire that aims to extract the need technical information while remaining simplified and easy to use. Figure 4 provides an overview of the application logic.

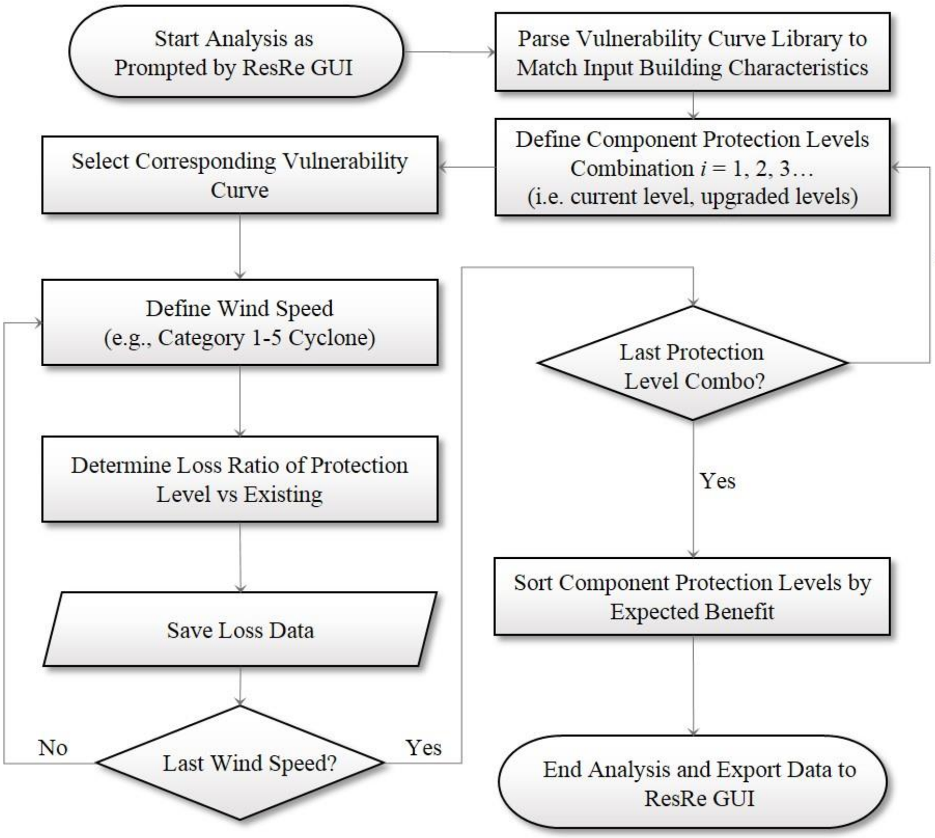


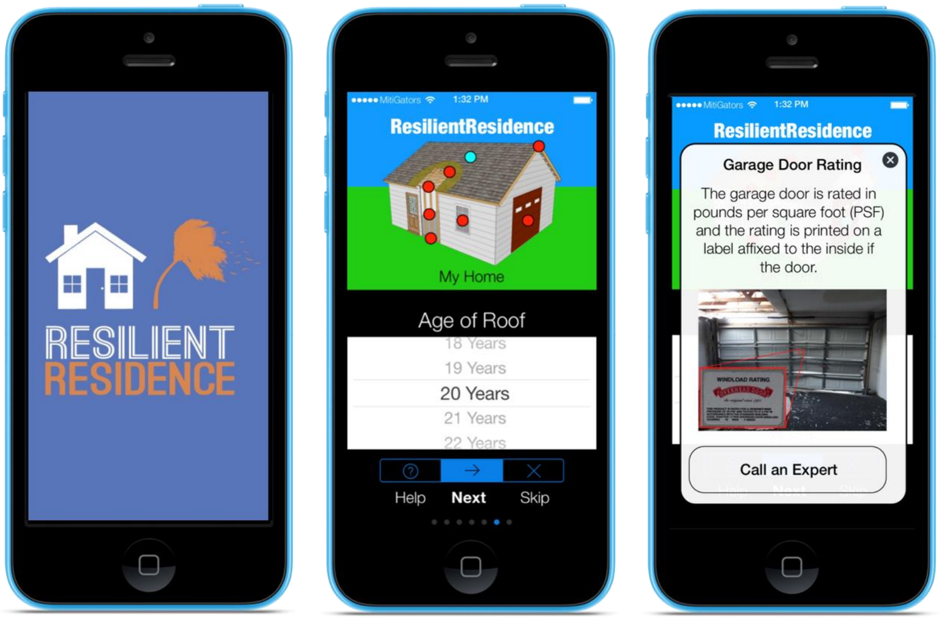
Figure 4. Vulnerability assessment and retrofit optimization program logic for ResilientResidence™

GRAPHIC USER INTERFACE (GUI)

While the technical engine for ResRe is critical to ensuring useful information is available to the user it must be coupled with a user interface that the majority of homeowners can use if the education and engagement goals of the app are to be realized. Ideally such an interface would be intuitive, seamless and easy to use, with minimal opportunities for user input errors, and minimal potential sources of frustration for a user who is likely to be unfamiliar with many of the concepts being explored (Leslie 2012). An initial app flow design that addresses these criteria has been developed into a prototype. In the prototype, the user launches the application from their smartphone device and is greeted with a homepage that serves as the base station for their experience. First time users are prompted to register an account and accept a legal disclaimer. All users are provided three options on the homepage (a) assess a new house, (b) review/update my existing houses, and (c) interact with the ResRe team.

If the user chooses to assess a new home, they proceed to start a new assessment of a home. If the user opts to review or update an existing house, the summary outputs from previous home assessments are provided, and the user is given the opportunity to edit their inputs, if necessary. The ‘Interact with the ResRe Team’ gives the user the opportunity to visit the social media pages associated with ResRe and email the ResRe team with questions or comments. This will allow the user to directly engage the researchers with questions or comments, as well as provide the user with up-to-date information about upcoming application updates, relevant research, and new findings. Providing this direct link between interested users and the research community is important to further facilitate the transfer of knowledge.

When assessing a new home, the user is prompted to: a) allow access to GPS coordinate capabilities available in the device to locate the house or b) manually input the address of the house being assessed. Once input, the user is guided through a series of screens that prompt the user for key baseline parameters describing the general aspects of the house. Examples include the age of home, number of stories, roof shape, and wall construction type. When available, this information will be automatically parsed from the local property appraiser database. If the user is unsure of any inputs, they are provided helpful content (e.g., illustrations of common roof types, or hints on how to determine the exterior wall material). Once baseline parameters of the home are defined, users are shown a graphical building representing the general characteristics of their home (Figure 5). Each dot point on the figure represents a critical building component within the vertical load path for wind hazards (e.g., roof covering, roof-to-wall connections, windows, entry doors and garage doors). Advanced options will also be available to allow selection of roof sheathing fasteners and gable-end bracing (if applicable). As shown in the figure, red circles will represent components that have not been defined by the user. Conversely, green circles with check marks will represent components that have been defined by the user.



The garage door is rated in pounds per square foot (PSF) and the rating is printed on a label affixed to the inside if the door.

Figure 5. Screen capture of current wire-frame version of ResilientResidence™ including building attribute selection (center) and attribute help screens (right)

In scenarios for which the user is unable to define the component, the program will default to the baseline values established by the home’s location, wall type, age, number of stories and roof type. Although accuracy of the results is maximized when the user is able to define all input parameters, the user is not precluded from receiving the vulnerability and mitigation outputs if components are not defined.

Upon successful definition of all components, the user is prompted to submit their home for assessment. Once selected, the user is provided an output report (Figure 6) consisting of:

1. The vulnerability of their current home to wind-related damage as monetary loss
2. Three optimized retrofit strategies that most effectively reduce damage potential
3. The expected monetary loss of the retrofitted home for a given wind-speed intensity level.

Estimated $91k damage as is.

Reduced to $58k with retrofits.

26% probability of a category 4 hurricane within 2 years.

- Upgrade to High Rated Shingles ⓘ ☑
- Upgrade Roof to 8D Nails ⓘ ☑
- Install Roof-to-Wall Straps ⓘ ☑

Figure 6. Screen capture of current wire-frame version of ResilientResidence™ output display

The three recommended mitigation methods are expressed on the screen as separate options that the user can select, either individually or in combination, to see how implementing the mitigation techniques reduces the vulnerability of their current home. The user can also see how effective the retrofits are for different hurricane scenarios, from Category 1 to Category 5 intensity. This aspect of the performance-based analysis allows the user to choose the performance they desire (economic losses) for a specific hazard level. When coupled with visualizations of hazard probabilities (not shown in current prototype), this becomes an even more powerful tool, allowing the user to make informed, engineering-based decisions on hazard mitigation levels with minimal training or expertise. The user is also presented with the option to send the full report, which includes all inputs and outputs, to outside stakeholders (i.e. insurance providers, etc.).

After completing the assessment users are provided several resources to guide in the implementation of the retrofit methods. These resources include, but are not limited to: the Federal Alliance for Safe Homes, Florida Department of Emergency Management, and the Insurance Institute for Business & Home Safety.

DISCUSSSION

Two parallel efforts in Florida (via David Prevatt and the University of Florida) and Queensland (via Daniel Smith and James Cook University) will commence in 2016 to identify drivers of homeowner engagement in each of these cyclone prone regions. The findings will be used to develop effective methods of incentivising homeowner engagement for use within Florida- and Queensland-based versions of the ResRe app. An alpha version of the decision-support tool will be constructed and tested for effectiveness in both locations. A comprehensive set of vetted vulnerability functions (e.g. HAZUS) does not currently exist in the public domain for Australia, however, these functions are currently in development at James Cook University in collaboration with Geoscience Australia and the Bushfire and Natural Hazards Cooperative Research Center. These functions will replace the HAZUS functions in the Queensland version of the application. The graphical interface will also be adapted to suit Queensland homeowners. Beyond direct benefits (i.e. increasing mitigation behavior, educating homeowners, informing risk-based pricing for insurance, etc.), widespread use of the application will generate large quantities of data on the age, location, building components, retrofit usage, etc. of the homes in these regions. This information will be used in aggregate form (with privacy filters) for a variety of research purposes, including identifying regions of higher vulnerability, etc. to inform public policy and emergency response and recovery.

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