RESQUAKE: Simulating Post-earthquake Damage in Philippine Homes Using Procedural Modeling

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ABSTRACT

Traditional post-earthquake training often relied on predefined scenarios that lacked the realism necessary to prepare trainees for the unpredictable scenarios of actual earthquakes. This research addressed this problem by introducing procedural modeling to create diverse models for simulations that reflected real-life post-earthquake situations. By leveraging procedural modeling, the researchers aimed to develop a comprehensive framework for procedurally generated post-earthquake models for rescue training operations on Philippine houses. Utilizing Houdini, a procedural modeling software, the researchers initially created a model incorporating standard architectural features of Philippine homes. These models were then refined under various earthquake scenarios, adjusting key parameters like magnitude. Preliminary results indicated that procedural modeling significantly enhanced the diversity of post-earthquake models for training scenarios, offering a more dynamic environment. Generating more training simulation environments rather than manually sculpting each led to a broader range of scenarios without a corresponding increase in time and resources needed to create them. This research held the potential to greatly enhance post-earthquake preparedness and response efforts in the Philippines and possibly other earthquake-prone regions.

Categories and Subject Descriptors

I.6.5 [**Simulation and Modeling**]: Model Development – *Modeling methodologies*

General Terms

Computing methodologies

Keywords

Procedural Modeling, Post-earthquake, Houdini

1. INTRODUCTION

Situated on the seismically active "Pacific Ring of Fire," the Philippines faced ongoing earthquake risks, underscoring the need for comprehensive disaster preparedness and agile response strategies. Effective post-disaster response, especially in the vital first 48 hours following an earthquake, is essential for saving lives and reducing damage [1,2]. The complexity and lack of in-depth understanding of post-disaster management call for enhanced strategies [3,4,5] in alignment with the United Nations (UN) Sendai Framework for Disaster Risk Reduction (DRR) goals of reducing hazard exposure, and improving preparedness and response [6]. To address this, the research titled "Resquake: Simulating Earthquake Damage In Philippine Homes Using Procedural Modeling" aimed to employ procedural modeling (PM) to innovate and diversify post-earthquake rescue operations. By utilizing PM techniques such as L-system, Voronoi, Material Fracture, and others, the study generated a multitude of models, which were detailed in the paper. The objective was to generate wide range of earthquake-damaged residential structures models to improve disaster response effectiveness, particularly in the critical initial hours post-disaster.

2. METHODOLOGY

The methodology of the study will be discussed in this section. Figure 1 presents the flowchart illustrating the study's methodology.

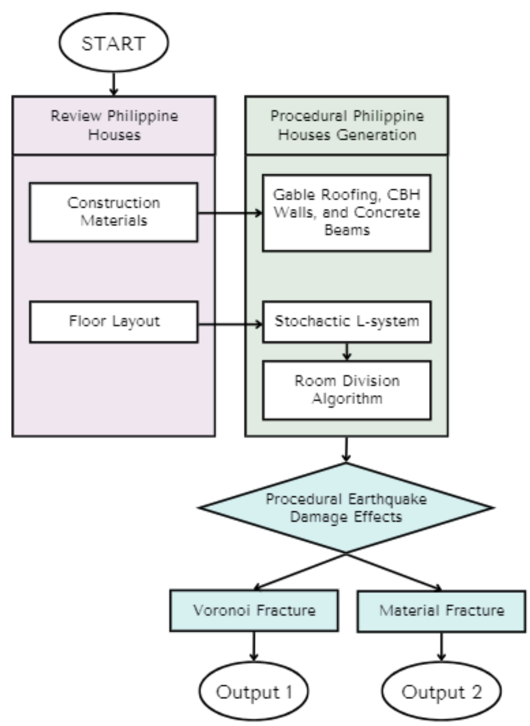

Figure 1. Resquake Methodology Process Diagram

The researchers conducted a literature review to identify the common construction materials of Philippines houses. Then, examined existing floor layouts sourced from real estate websites.

The researchers then employed procedural generation techniques to create detailed models of Philippine houses. This involved integrating specific architectural features such as gable roofing, concrete hollow block (CHB) walls, and concrete beams. The complexity of floor layouts was addressed using stochastic L-systems. Additionally, a room division algorithm was implemented to partition the generated spaces into distinct rooms.

By incorporating procedural modeling techniques specifically Material Fracture and Voronoi Fracture, earthquake damages were simulated in the generated houses. The researchers systematically evaluated each procedural modeling technique, considering caching time per 100 frames.

3. RESULTS AND DISCUSSION

This section presents the outcomes of the procedural generation of Philippine houses along with the post-earthquake damage effects on these models. It will detail the procedural generation and demonstrate the variability and efficiency of this approach. Through a comparative analysis, the resilience of the generated structures against earthquakes will be evaluated based on the Richter scale magnitude.

3.1 Characteristics of Philippine Houses

3.1.1 Construction Materials

In analyzing the architecture of urban residential areas within the Philippines, a distinct pattern emerged, characterized by a reliance on concrete materials and designs tailored to local climate and urban demands. The structural framework, notably beams, columns, and walls, predominantly utilize reinforced concrete and concrete hollow blocks (CHB), highlighting a national preference for these materials due to their durability and accessibility [7, 8,9]. Moreover, the roofing of these residences further demonstrates an adaptation to local conditions, employing materials such as tin and designs like gable roofs to offer practical, cost-effective solutions for weather protection and aesthetic preferences [10,11]. An extensive survey across 15 municipalities elucidated the diversity in roof designs, with gable, mono-slope, and hip roofs dominating the landscape, accounting for significant portions of the observed structures [12]. This comprehensive analysis formed a solid foundation for developing 3D models that accurately reflected Philippine residential architectures. Incorporating reinforced concrete, CHB, and tin gable-shaped roofing into 3D models ensured an authentic representation of the Philippines' common residential architecture.

3.1.2 Floor Layout

A floor plan from [13] showed that a basic Filipino floor layout was divided into public and private spaces. The public space comprised the living room, dining area, and kitchen. It was also evident that the entrance was where the door was located. The private space consisted of two bedrooms and a bathroom.

A comprehensive two-story floor plan adapted from [14] delineated the spatial distribution between public and private areas within a Philippine residential structure. The ground floor was exclusively allocated for public use, encompassing the kitchen, living, and dining areas. Conversely, the second floor was devoted to private spaces, primarily the bedrooms.

The floor layouts from [13] and [14] illustrated the division between public and private spaces in Philippine Homes. These plans served as a blueprint for generating 3D models, ensuring an accurate representation of typical Philippine residential architecture in procedural model creation.

3.2 Philippine Houses Generation

Procedural modeling was an automated computer graphics technique that employed algorithms and rules to generate complex models and textures, enabling the efficient creation of extensive environments like cities and landscapes with minimal manual effort [15,16,18]. Specifically, procedural modeling was utilized to achieve the diverse generation of Philippine houses and to apply different earthquake magnitude effects to those structures, showcasing its applicability in simulating real-world scenarios and architectural diversity. After examining the common characteristics of Philippine houses, those features served as the foundational model for procedurally generated houses.

3.2.1 Floor Layout Generation

In exploring innovative methodologies for floor layout generation, the utilization of Lindenmayer Systems (L-systems) presents a compelling avenue for random architectural design automation [17]. Leveraging their rule-based generation capabilities to automate and diversify design possibilities [15,17,18]. The implementation of the L-system in this study was defined by a set of production rules aimed at generating floor layouts through a stochastic approach.

$$A \rightarrow F+A:0.5$$

$$A \rightarrow F-A:0.5$$

In these rules, A represents the starting variable, F denotes a forward movement — and + symbolizes turns in left and right directions with an equal probability of 0.5 for each. This stochastic approach to L-system-based floor layout generation not only automates the design process but also introduces a level of variation that is difficult to achieve through manual design methods [18,19].

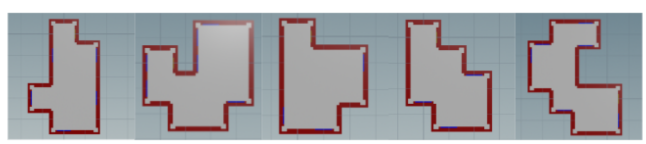

Figure 2. Random Floor Layout Generated Using L-system

Figure 2 showed a random sample of 5 different floor layouts that were generated using an L-system through a stochastic approach. Each of the 5 layouts was unique, indicating that the system could generate a wide variety of floor plans.

3.2.2 Interior Generation

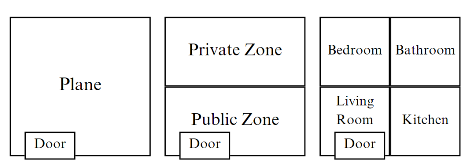

Figure 3. Algorithm for 1-Storey House Division

Figure 3 illustrates a Floor layout Division algorithm for floor area division within a house, categorizing spaces into Public and

Private zones. The Public space was defined by the door position, branching into a Living Room and Kitchen, while the Private space comprised a Bedroom and Bathroom.

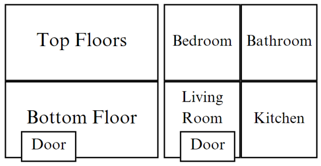

Figure 4. Algorithm for 2 or more Storey House Division

Figure 4 detailed a corresponding Floor layout Division algorithm for multi-story houses, applicable when the floor number exceeded one. It categorized the first floor entirely as a Public space, which included a Living Room and Kitchen, typically near the entrance. The algorithm then designated the remaining floors exclusively as Private spaces, composed of Bedrooms and Bathrooms.

Figures 3 and 4 presented a rule-based algorithm that was employed in a procedural modeling system for generating architectural floor plans. Essentially, the process followed a treemap subdivision with some intersection and dimensioning operations to deal with the division of the rectangular polygon.

3.3 Simulating Earthquake Damage

This section examined the application of procedural generation techniques for the realistic simulation of earthquake damage on generated house models, facilitating the efficient creation of models encompassing a spectrum of earthquake impacts, from minor damages to substantial structural failures.

3.3.1 Voronoi Fracture

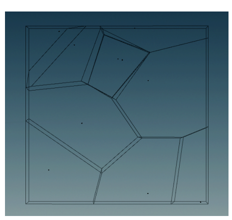

Figure 5. Voronoi

Voronoi diagrams are employed to simulate the fracture process in concrete. These simulations help in understanding the crack morphology and stress-strain responses in concrete, illustrating how the Voronoi-based models can influence crack initiation and growth [20]. The level of detail in Voronoi fracture simulations can be quite high, with the ability to model complex crack patterns and interactions within heterogeneous materials like concrete. These models account for the realistic representation of aggregates, enabling detailed analysis of fracture mechanisms under various loading conditions, including static and dynamic tensile loads [21]. The Voronoi Fracture parameters could be adjusted to represent different intensities and types of seismic damage, from fine cracks indicative of minor tremors to extensive fragmentation resulting from a major quake. The study demonstrated that using a density volume, derived from an object's geometry with IsoOffset, to scatter points was an adaptable approach for generating cell points. Modifying the density inside the volume prior to scattering facilitated the accumulation of more points in designated areas of the object. Consequently, in regions where the point density was higher, the Fracture SOP was configured to produce a larger number of smaller fragments.

3.3.2 RBD Material Fracture

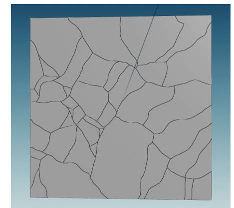

Figure 6. Material Fracture Pattern

The process of RBD material fracture in Houdini involved using various tools and solvers provided within the software to simulate the physical behavior of materials under stress or impact. The parameters governing the fracture simulations, such as force, direction, and material type, could be finely tuned to simulate specific earthquake scenarios. This level of control ensures that the simulated damage closely matches real-world observations or theoretical predictions [22]. The Fracture Level will control how many cuts your object will have. Increasing this number will add more fractures to the existing fractured pieces, breaking each chunk into smaller pieces [22].

3.3.3 Testing

In the house model generation, it was observed that procedural generation techniques offered a significant speed advantage. Specifically, the study achieved significantly faster layout generation by employing simpler rules, such as stochastic distributions A=F+A:0.5 and A=F-A:0.5, as detailed in Section 2.2.1. However, it was important to note that while L-systems with defined rules could offer advantages such as enhanced randomness and the capacity to manage complex shapes, they also presented certain limitations. These limitations encompassed the fact that increased seeding could lead to the creation of plant branch patterns. Despite these challenges, L-systems might still have been a viable option for projects where such attributes were deemed less critical. However, within the scope of that study, the algorithm had proven efficient for initiating procedural generation of residential layouts with considerations for post-earthquake damages.

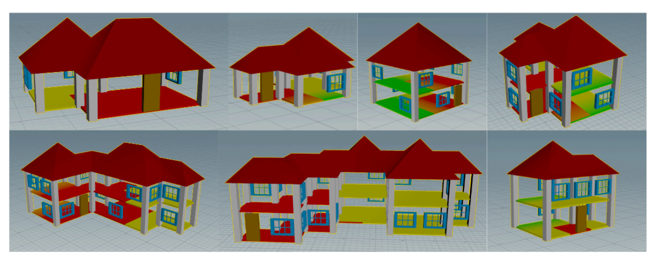

Figure 7. Samples of Procedurally Generated Houses

In terms of performance, the procedural generation method had demonstrated the capability to generate 46 quality models out of 50. This indicated a relatively high success rate, yet it also highlighted the potential for refining the model generation process to reduce the occurrence of inadequate outcomes.

The researchers had then compared the efficiency of Voronoi and Material Fracture procedural modeling techniques in Houdini SideFX for simulating fractures in a house's beams and walls. These methods were evaluated based on the time required to save the data to disk and the caching time per 100 frames.

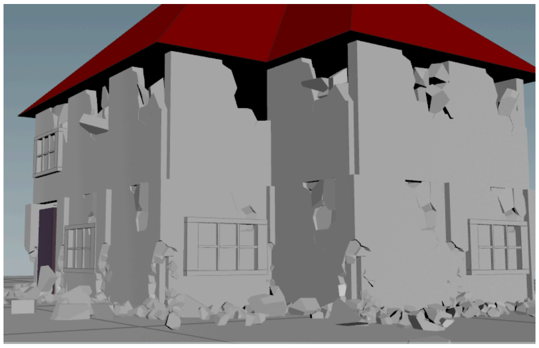

Figure 8. Earthquake Damages Using Procedural Modeling

The Voronoi Fracture method, known for generating natural-looking fractures, was applied to the house's beams and walls. It quickly computed break patterns by creating Voronoi cells around distributed points within the object's volume. Conversely, the Material Fracture technique, which accounted for the material's physical properties, offered a more realistic fragmentation, which was important for detailed visualizations.

Table 1. Data Storing Efficiency Comparison

Procedural Modelling Technique	Beam	Wall
Material Fracture	5.26 seconds	4.74 seconds
Voronoi Fracture	2.45 seconds	1.76 seconds

In terms of data storing efficiency in Table 1, Voronoi Fracture outperformed Material Fracture, taking 2.45 seconds for beams and 1.76 seconds for walls, compared to the 5.26 and 4.74 seconds taken by Material Fracture, respectively. This suggests that Voronoi Fracture is a more efficient technique in terms of processing time for these specific applications.

Table 2. Caching Time Efficiency Per 100 Frames Comparison

Procedural Modelling Technique	Whole House	Beam	Wall
Material Fracture	23.14 seconds	4.41 seconds	11.9 seconds
Voronoi Fracture	8.73 seconds	4.18 seconds	4.34 seconds

According to Table 2, the Voronoi fracture procedural modeling technique demonstrates significantly higher efficiency when compared to the Material fracture method. The time taken to process 100 frames for a whole house is 8.73 seconds with the Voronoi fracture, which is much less than the 23.14 seconds required for the Material fracture. When it comes to a beam, the Voronoi fracture method only needs 4.18 seconds, whereas the Material fracture takes 4.41 seconds, showing a slight but notable efficiency gain. In the case of a wall, the Voronoi fracture's time efficiency is 4.34 seconds compared to the Material fracture's 11.9 seconds. These gaps highlight the Voronoi fracture's superior efficiency, with time savings of 14.41 seconds for a whole house, 0.23 seconds for a beam, and 7.56 seconds for a wall.

4. CONCLUSION

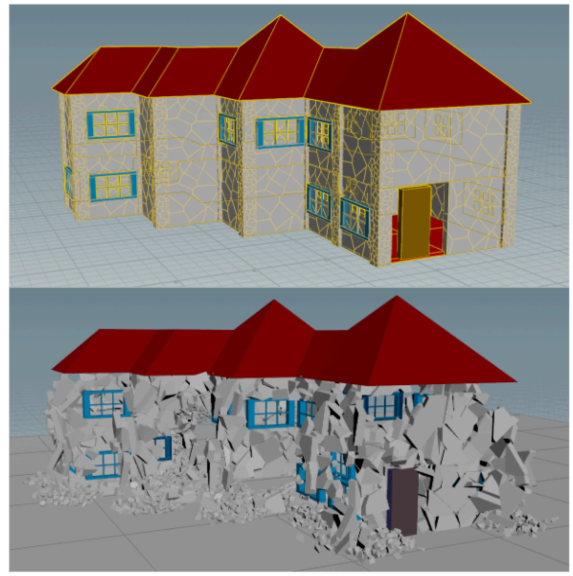

Figure 9. Earthquake Damages Using Procedural Modeling

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