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Towards the Integration of Socioeconomic Impact and Recovery Modeling into High-Resolution Regional Earthquake Simulations

A. Zsarnóczay[1] and G.G. Deierlein[2]

ABSTRACT

This paper highlights two important areas where substantial improvements are needed to support the expansion of computational disaster simulation to enable quantitative investigation of broad impacts on communities and the recovery of cities after earthquakes. The natural hazards engineering community needs i) robust and standardized workflows for high-resolution regional earthquake simulation to foster sharing and re-use of research outputs, and ii) publicly available, rich, high-resolution data on the built environment and population demographics. The NHERI SimCenter is well positioned and seeks to facilitate advances in both areas while also technically supporting researchers who work at the interface of engineering and social science. The paper presents the relevant research tools and initiatives developed at the SimCenter and our vision for future work in these areas.

Introduction

Conventional methods in regional seismic risk assessment, such as the Hazus earthquake methodology [1], are complemented today by higher resolution approaches (e.g., [2]) that aspire to make the features developed for performance-based design and assessment [3] of individual structures available in regional-scale earthquake simulations. This next generation of regional simulations can investigate each element of the built environment considering characteristics of their key components to provide a specific, more faithful description of the range of possible structural behaviors anticipated in a natural hazard event and the damages expected to develop as a result (e.g., [4]). Given sufficient resources, engineers are already able to model every relevant asset (e.g., buildings, segments of buried pipelines, or bridges in a transportation network) in a region and obtain rich information on the expected damage in one or more plausible earthquake scenarios (e.g. [5, 6]). The computational and human resources required for such simulations are expected to decrease rapidly in the next few years, making them widely available in both research and practice.

The goal of regional earthquake simulation is often to provide information that can support natural hazard risk mitigation and local policymaking. Rather than discussing damages and measures of structural performance used by engineers, these simulations should go farther and investigate the consequences of such

[1] Research Engineer, Dept. of Civil and Env. Eng., Stanford University, Stanford CA 94305 (email: adamzs@stanford.edu)
[2] Professor, Dept. of Civil and Environmental Engineering, Stanford University, Stanford CA 94305

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damages in the context of a system of assets that serve a network of local communities. The final results should focus on how communities are expected to respond and recover from the shock introduced by the natural hazard event. Such an extension of high-resolution regional simulations presents challenges from both a data and a modeling perspective. Tackling these challenges will require closer collaboration across multiple relevant disciplines; development of active partnerships and working groups that involve academic researchers, practitioners, and representatives of the public sector; as well as commitment to more disciplined management, standardization, and open exchange of critical data.

The Computational Modeling and Simulation Center (SimCenter) at UC Berkeley [7] is well positioned and seeks to facilitate such interactions at the interface of engineering and the social sciences. Funded by the National Science Foundation under the Natural Hazards Engineering Research Infrastructure, the SimCenter has been leveraging past research and development and integrating models and data from the physical sciences and engineering into computational workflows to help advance new lines of research in Natural Hazards Engineering (NHE). This paper presents two primary thrusts that we consider important to expand our framework to the social sciences and support developing the capability of quantitative assessment of the recovery and resilience of communities.

Robust and Reproducible Regional Disaster Simulations

Engineers simulate damage to the built environment using a complex sequence of applications, where, in each step, an application processes data from the previous steps and passes its outputs to the next step. These sets of applications are often referred to as workflows. There are dozens of applications available for each step of these workflows that can handle tasks from the estimation of the intensity of ground shaking, through the simulation of structural behavior, to the assessment of expected damages. Different research groups and practitioners choose different applications, and they often also develop in-house tools to assemble their own unique disaster simulation workflow. Each of these different workflows has its own implicit assumptions which makes it difficult to compare results from various research groups. Unless the workflows and the corresponding assumptions are explicitly described, it is typically not possible for an independent research group to reproduce the results and extend an earlier study. This status quo leads to siloed research work and hinders collaboration already within the engineering community.

The SimCenter has been developing an application framework (Figure 1, [2]) to provide a common, standardized, and robust platform for the NHE community where researchers can assemble various workflows for regional disaster simulation. The interfaces between the applications are developed and maintained by the SimCenter to ensure seamless end-to-end data transfer. This is an open framework; each step of the workflow can be performed by various applications and the set of available applications is continually extended according to the needs of the community. Regardless of the assembled workflow, both the inputs and the results are presented in a standardized format that fosters sharing them with others across disciplinary boundaries and encourage developing applications in social sciences that build on the outputs of engineering simulations.

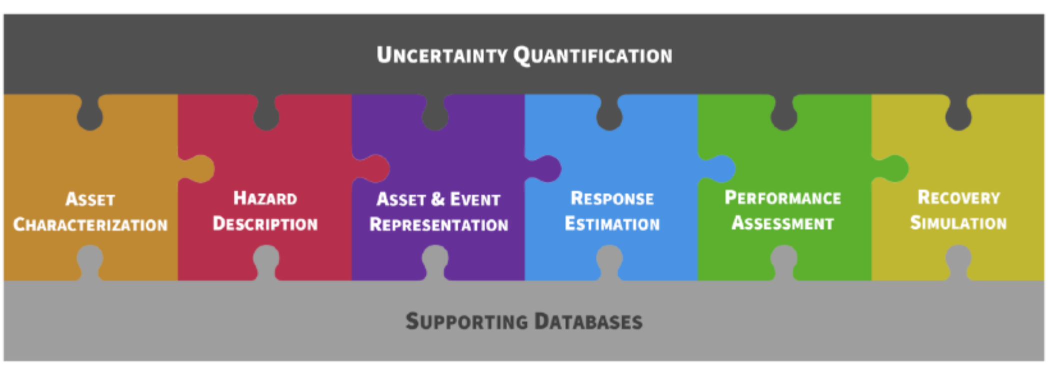

Figure 1. Conceptual organization of SimCenter's application framework for disaster simulation workflows

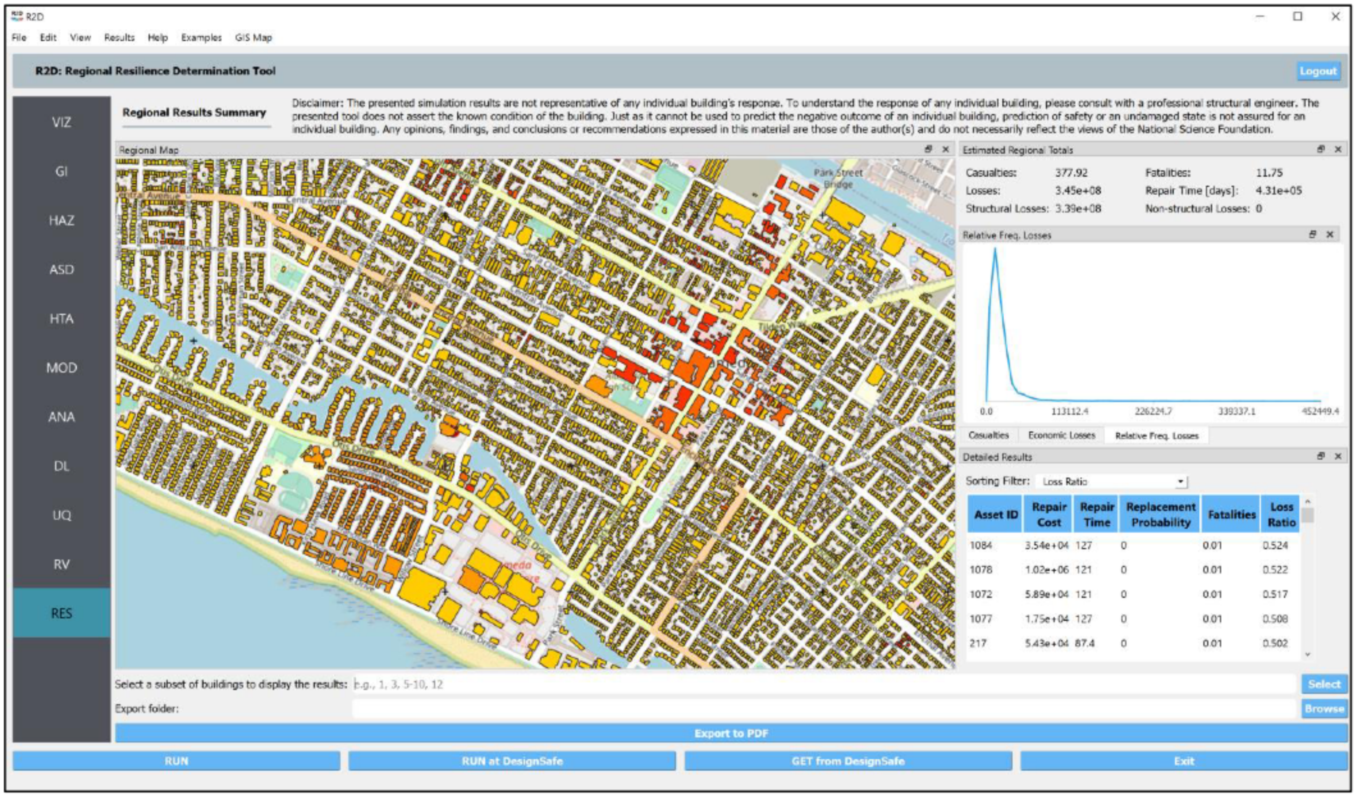

Figure 2. The R2D Tool allows researchers to run custom workflows on high performance computing clusters and produces outputs in a standardized format that facilitates sharing and post-processing.

The SimCenter also develops the R2D Tool (Figure 2, [8]), an open source and publicly available desktop application that provides convenient access to the workflows provided by the application framework and directly runs large simulations on high performance computing clusters, hiding the complexity of setting up and managing such remote calculations from the user. Currently, the supported workflows can estimate damage and direct consequences (i.e., losses based only on the damage to individual buildings). Detailed online documentation [9] facilitates learning the usage of the tool and several regional simulation examples are available to serve as templates for new studies. The potential in flexible workflows with standardized outputs and convenient access to large computational resources is already being realized by researchers who work at the interface of engineering and social science (e.g., [10, 11]). The SimCenter strives to connect with more experts in that interface and support their work by integrating the corresponding models into the application framework and the R2D Tool so that we can enable collaborative hazard-to-recovery simulations with the same kind of transparency and robustness that we have available for regional damage assessments today.

Publicly Available, High-Quality Exposure Data

The investigation of complex interdependencies through consequence and recovery models requires richer information at a higher resolution than what is available today. Public data about the built environment and population demographics needs to be collected from several sources that provide it in incompatible formats and resolutions. Integrating these into a single database that characterizes exposure in a region is not trivial. The SimCenter is developing tools to facilitate the collection, review, integration, and augmentation of exposure data [12]. We are creating rulesets based on local building codes and training machine learning models to use satellite and streetview images to infer missing attributes of buildings and other structures [13, 14]. Every tool supports and encourages researchers to recognize and quantify uncertainties in structural and demographic characteristics. The resulting exposure data follows a standardized, well-documented schema compatible with the R2D Tool.

Table 1. Ontology proposed by the SimCenter to facilitate data discovery in natural hazards engineering

Natural Hazard	Phase	Context	Origin	Provider	Access
Earthquake & Geo	Exposure	Natural env.	Simulation	Public sector	Private
Wind	Hazard	Built env.	Experiment	Private sector	Shared
Water	Damage	Households	Observation	Academic entity	Published
Climate	Consequences	Businesses			Public
Fire	Recovery	Services			

The SimCenter held a workshop with experts from a diverse set of disciplines and roles in NHE to identify modeling and data needs to enable simulation of broad impacts of natural hazard events and post-disaster recovery [15]. Participants identified important gaps in the available exposure information that are not filled even after applying machine learning techniques to augment the combination of publicly available datasets. Several databases with valuable information are protected (e.g., data on lifelines) or proprietary (e.g., data on businesses) and sensitive demographic data on household characteristics that are critical to infer socioeconomic vulnerabilities and post-disaster behavior will almost surely never be available at a household or building resolution. Resolving these problems requires a concerted effort from many parties.

Experts in our workshop highlighted better data sharing and data discovery in the NHE community as one of the important needs to support such collaboration because currently, many researchers can only rely on data from federal agencies for their work. The SimCenter responds to this need by creating web-based, extensible, federated databases for the NHE community in collaboration with the NHERI DesignSafe-CI [16, 17]. We also encourage the community to develop an ontology specifically for NHE data. A commonly used ontology would improve the utility of data labels and make data discovery more efficient. The proposed first version of such an ontology was developed by the SimCenter based on information about the types of data used by participants of our workshop. Table 1 summarizes the labels only; more details and supporting data are available in [15, 18].

Concluding Remarks

This paper presented several contributions from the NHERI SimCenter that support the expansion of computational disaster simulations to integrate quantitative analyses of social science impacts and recovery modeling into an existing robust framework of probabilistic regional natural hazard risk assessment. Our objective is to enable running end-to-end simulation workflows that perform tasks from the description of the hazard to the characterization of the recovery process. The SimCenter actively seeks input from the NHE community and established a working group of diverse experts that provides guidance to the project specifically on developments related to the topic of this paper. We welcome contributions and feedback from interested researchers and practitioners and encourage those working in this area to contact us to see if there is an opportunity for collaboration.

Acknowledgments

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