DISTRIBUTED OBJECT-BASED SOFTWARE ENVIRONMENT FOR URBAN SYSTEMS INTEGRATED SIMULATION

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ABSTRACT

The world is becoming predominantly urban. Such urban systems are threatened by the risk of urban-scale hazards. However, hazard simulation is one of the promoting methods that empower preparedness for the on-time scenario which in turn help to reduce human, economy, culture, and environment losses.

This paper presents a Distributed Object-based Software Environment (DOSE) for urban systems integrated simulation. Integrated simulation means a complete city can be simulated: buildings, bridges, pipelines, etc. All are in one simulation. Then, hazard action and in turn damage and losses that have been resulted are simulated.

To construct such environment; an architecture has been designed using currently available computer, communication, and information technologies in addition to civil engineering technology. Two main problem statements have been addressed here. First is software environment architecture. Second is software environment scalability. In this paper an Integrated Earthquake Simulation (IES) has been developed and presented as an example application for the software environment. Numerical experiment has been conducted for part of Bunkyo city, Japan, with domain size of (800x600 [m]) and results illustrated spatial variation of ground motion and associated structural damage.

KEY WORDS

urban systems, urban-scale hazard, integrated simulation, software environment, environment architecture, scalability, earthquake simulation, ground motion, structural damage.

INTRODUCTION

Sustainable urban development is now a worldwide pressing issue. Yet, progress in urban disaster preparedness and mitigation has been slow, especially in developing countries. The rate of increase of urban risk caused by explosive population growth far out-balances the

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progress made in mitigation. In addition, advances made by scientists are slow in reaching the end-users because of communication gap between researchers and practitioners on one side and those who need to understand knowledge and employ it (end-user) on the other side. In developing countries where urban vulnerabilities are increasing because of, often, lack of resources, the gap is even wider.

Research done by Earthquake and Megacities Initiative, EMI, organization has found that rapid growth of large cities, their increasing vulnerability to disasters and urgent need to pay attention of all stakeholders and particularly local and central government authorities on risk reduction in interest of social and economic stability requires:

1. Recognition of earthquake risk and commitment to preparedness, prevention and mitigation as the most efficient approach to reducing the human and economic losses.
2. Institutionalization of risk mitigation in urban planning and development of cities.
3. Empowerment and strengthening of local capacity by allocation of resources, multi-disciplinary training and decentralization of disaster management activities.
4. Improved interaction between researchers, practitioners and end-users, and improved communication of technical and scientific knowledge to non-scientific audiences.
5. Effective partnership among organizations that contribute to sustainable development.

In recognition of these factors, authors did start a mission for building Distributed Object-based Software Environment (DOSE) for urban systems integrated simulation. It is a technology-based collaboration platform tool for supporting transparent, decentralized integration of heterogeneous computational models to address various aspects of a complex system (urban system) problem. One of the unique challenges of building large system simulations, urban system, is that their boundaries, scope, or definition are ill defined and, undoubtedly, will evolve considerably over time. Thus traditional system modeling approaches present great difficulties because of their explicit system definition requirements. The DOSE environment allows distributed computational elements to be linked in a decentralized ad hoc manner so that an integrated simulation can grow and evolve in an organic fashion.

BACKGROUND AND OBJECTIVE

A comprehensive rescue simulation system for earthquake disaster reduction has been developed in the RoboCupRescue simulation project (Tadokoro 2000 and Takahashi 2000) where on-going efforts intend to make the simulation system more realistic for search and rescue at the first chaotic stage of disaster. The research in this area is expected to be promoted by world-wide cooperation by means of periodic competition and evaluation conferences, the international RoboCupRescue competition held by the RoboCup Federation.

In 2002, the ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan started the special project for Earthquake Disaster Mitigation in Urban Areas of five year term, with some large amount of budget, more than three billion yen per year. This project encompasses themes on disaster mitigation and preparedness, ranging from improvement of building architecture to exploitation of robotics and information technology

(IT). One of the main topics of the IT exploitation subproject is the development of an integrated earthquake disaster simulation system which is now being conducted by (Takeuchi, et at. 2003). It is worthy to note that the work done for disaster simulation such as: fire spreading and fighting, human rescue activities, mass evacuation, risk assessment and communication, traffic congestion, etc are well-developed and have significant contribution; however, the key input data, seismic intensity and response, are empirical data.

Consequently, there is great need to emphasis on earthquake action simulation, scientific-analysis-based simulation, where the resulted seismic intensity and response can be inputted, easily, for disaster simulation to get more reliable and realistic disaster scenario and hence more realistic and effective preparedness and mitigation actions.

A strong ground motion simulator has been developed by (Ichimura and Hori 1998) to numerically simulate wave propagation process from a fault to a target site achieving higher spatial and temporal resolution. Based on this strong ground motion simulator and geographic information system (GIS), an earthquake has been simulated in a virtual metropolis by (Yang, et al. 2002). A simulation system, called Integrated Earthquake Simulation, has been proposed by (Ichimura, et al. 2004) to combine various numerical simulations of earthquake and structural behavior with data stored in GIS. Once high spatial and temporal resolution of strong ground motion is achieved, all structures within a target area are modeled by using GIS data, such that a digital city is constructed in computer. However, drawbacks of such integrated system can be summarized as follow:

1. Lack of interoperability, sticking to a set of numerical simulation services.

2. Procedur-based modeling, does not help Object-based interoperability.

3. Lack of distributed simulation service.

4. Lack of scalability, accepting simplified as well as sophysticated modeling.

The objective of this research work is to design the DOSE environment architecture in a manner that is able to overcome the aforementioned drawbacks based on the-state-of-the-art technologies in addition to building environment that is capable to simulate other hazards else than earthquake. Interdisciplinary collaboration is a merit in this research work.

METHODOLOGY

An object-based integration technique has been used to design the DOSE environment architecture; in addition, it has been designed in a layered structure which in turn enables further definition and extension to different hazard actions. On the other hand, message passing interface (MPI) technique has been employed to parallelize computations inside the environment and to enable scalability. MPI in turn has enabled clusters, LAN, and WAN computations, i.e. distributed environment. It is worthy to note that methodology for enabling interoperability in the DOSE environment is beyond the scope of this research paper.

Hereafter, the DOSE environment architecture has been explained; in addition to, an example application for the DOSE environment to develop the aforementioned integrated earthquake simulation. Analysis for Bunkyo city, Japan, with domain size (800x600 [m]) has been conducted under earthquake hazard.

DOSE ENVIRONMENT ARCHITECTURE

Figure 1 shows the DOSE environment architecture. It provides a modular structure for environment components. There are four conceptual layers within the architecture which use a strict "Gravity Rule" referencing principle, see Figure 1. Within each conceptual layer a set of environment classes are defined.

The four conceptual layers are defined as follow:

1. The first conceptual layer provides Resource classes used by classes in the higher levels, it is a container for computer technology.
2. The second conceptual layer provides a Core layer. This Core layer contains concepts which are common for all numerical analysis services, it is a container for civil engineering technology.
3. The third conceptual layer provides a Domain layer. This Domain layer contains concepts which are domain-dependent, it is a container for whatever domain in the urban system that is needed to be simulated under hazard risk.
4. Finally, the fourth conceptual layer provides an Interface layer. This Interface layer contains concepts which enable interface with numerical analysis services, it is a container for both computer and comunication technology.

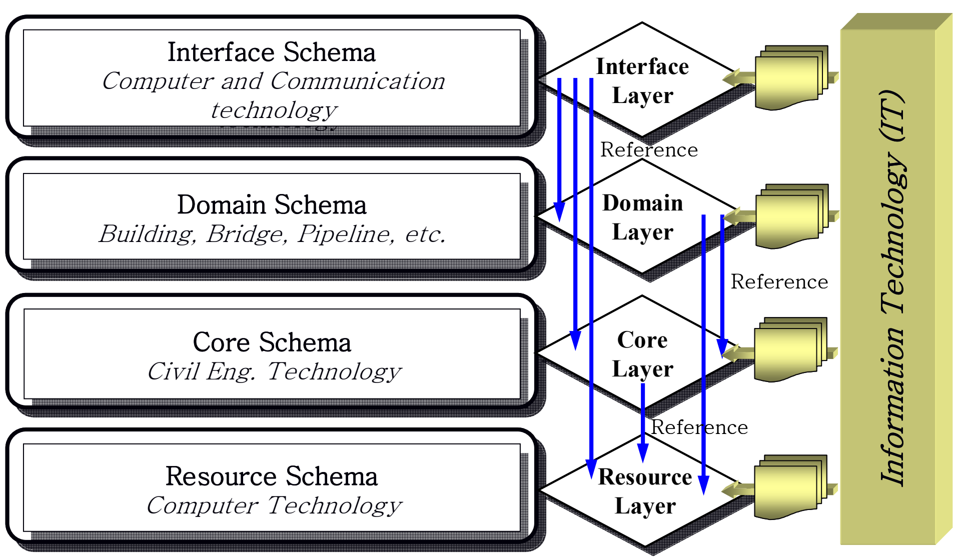

Figure 1: The DOSE Environment Architecture

As a result of that DOSE environment is desired to be object-based; an Object-Oriented Programming has been employed to derive different objects required by the software environment throughout instantiation from its relevant classes.

DOSE environment has been developed using a set of principles governing its organization and structure. These principles focus on basic requirements and can be summarized as:

1. Provide a modular structure to the environment.
2. Provide a framework for sharing information between different numerical simulation services, software packages, within the environment.
3. Enable automation of environment interface executables generation.
4. Ease the continued maintenance and development of the environment.
5. Enable data modellers to reuse environment components.
6. Facilitates the provision of better upward compatibility between environment releases.

Hereafter, brief explanation for DOSE environment interface layer has been introduced.

INTERFACE LAYER

DOSE environment architecture has been designed so that each domain object is able to manipulate its physical and FEM data and hence knows very well his rights and duties based on environment constitution, environment architecture. Domain object's right is that it has to be provided by answer for all questions it may ask throughout its life inside DOSE environment simulation. On the other hand, domain object's duty is that it has to answer all questions that may be asked to it throughout its life inside DOSE environment simulation. Questions contents and formats for answers have already been defined in DOSE environment; consequently, no domain object has to worry about answering any question throughout the defined environment border.

The number of structures per domain could by extremely large. In addition, enabled possibility of using wide range of available numerical analysis services increases the difficulty because some of them are sophisticated, time consuming. Accordingly, parallel processing has been employed in the DOSE environment simulation execution.

The Object-based nature of DOSE environment has enabled decomposition of the global process to number of processes each process is responsible for one task and the global task has been retrieved throughout interaction among simulation processes. Accordingly, each domain has been assigned number of processes to conduct its tasks and globally all domains have been analyzed at the same time, i.e. bridges, buildings, and so on have been analyzed at the same time, hence significant reduction in run-time has been resulted.

From this perspective, interface layer of DOSE environment is responsible to accomplish the execution throughout interfacing between simulation domains and inter-domain processes. Interface layer consists of three parts: KeyInterfaceBasic, KeyInterfaceExecutable, and KeyInterfaceConverter. Where "Key" is a keyword describes the application in question, i.e. for Integrated Earthquake Simulation this keyword is "Ies". It is worthy to note that KeyInterfaceConverter provides interoperability and it is beyond scope of this paper.

KeyInterfaceBasic is the part that responsible for building up required interface concepts that are needed for parallel execution and interaction among different simulation processes. Interface class encapsulates interface concepts for domains and inter-domain processes.

KeyInterfaceExecutables provides interface executable that acts as a mediator between environment simulation and numerical analysis service. Accordingly, interface executable has to be able to understand both DOSE environment language and numerical analysis service language to accomplish the required domains as well as inter-domain interactions. It is an encapsulation for the DOSE environment simulation execution. Each inter-domain process has been assigned an interface executable which in turn assigned an interface object of the relevant domain. Consequently, many processes have been resulted. Domains and inter-domain interaction has been implemented based on message passing interface (MPI) technique where message is a data mail that contains all data which prepared to be sent during interaction. A communicator has been provided to handle interaction. A communicator is a virtual network pipe through which message, data mail, can pass from and to a process that sharing communication through this communicator. This virtual network pipe has number of branches equal to the number of processes which are sharing communication. The virtual network pipe branch may act as inlet only, outlet only, or both based on run-time scenario of environment simulation. MPI provides default communicator namely MPI_COMM_WORLD. However, to avoid any communication interruption each domain has been afforded a communicator and globally the overall processes have been communicated by the default one. A Control Room namely KeyEnvironmentControlRoom has been provided to control and schedule interactions among all processes. Figure 2 illustrates the DOSE environment simulation processes and communicators (XYZ indicates any domain name, n is number of domains, $n > i \geq 0$).

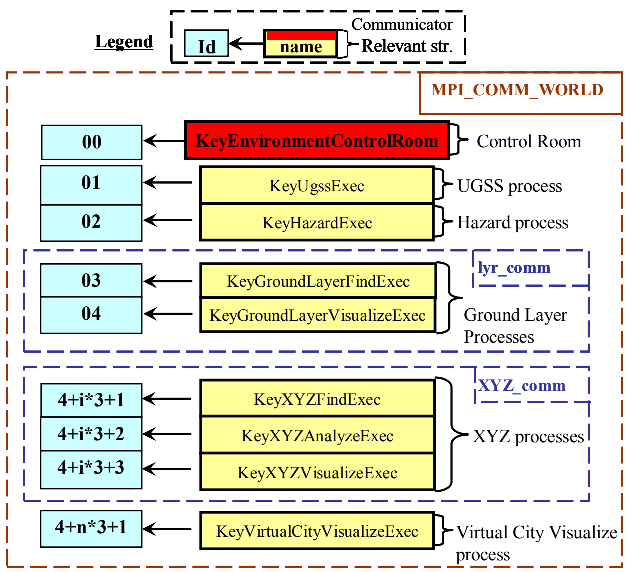

Figure 2: DOSE Environment Processes Identification and Communicators

DOSE APPLICATION FOR EARTHQUAKE HAZARD SIMULATION

Figure 3 illustrates three holistically classified steps for earthquake hazard simulation application. In the first step, DOSE environment is initialized by data. In the second step, seismic analysis is done. In the third step, damage index and distribution are calculated.

Damage index in turn is used to represent global dynamic image and damage distribution image which are used to simulate the on-time earthquake hazard scenario. It is worthy to note that in seismic analysis step earthquake causes and effects have been integrated. Causes are represented in earthquake ground motion (EGM) which in turn highly dependent on underground soil structure (UGSS). Numerical analysis services are integrated to model UGSS and to simulate the dependent EGM. Interaction between UGSS and EGM is carried out to resolve the aforementioned dependency and to result in the desired at-site ground motion which in turn has the at-site characteristic. On the other hand, earthquake effects are represented in response of different structures that are stroked by the earthquake. Numerical analysis services are integrated to model and to simulate structures response.

A numerical experiment has been conducted for Bunkyo city, Japan, with domain size of (800x600 [m]). It is worthy to note that detailed explanation for numerical analysis services that are used for constructing UGSS and simulating EGM can be found in (Ichimura and Hori 1998, Yang, et al. 2002) as a series of past research work on EGM simulation and UGSS modeling, respectively. In addition, it is important to keep in mind that DOSE environment interface layer can replace any service by more simplified or sophisticated one based on the defined interoperability in KeyInterfaceConverter. Accordingly, numerical analysis services act as plug-in.

A digital city with domain dimensions of (800x600 [m]) is constructed by using stored GIS and CAD data for each building. An aerial view for Bunkyo city, by GoogleEarth, and a perspective for the constructed static digital city are shown in Figure 4. Vertical incidence of Ricker wavelet has been inputted to the base of target domain; moreover, ground surface topography has been taken into account by EGM simulator. Figure 5 shows spatial variation of time history for input ground acceleration at each building, at-site ground motion.

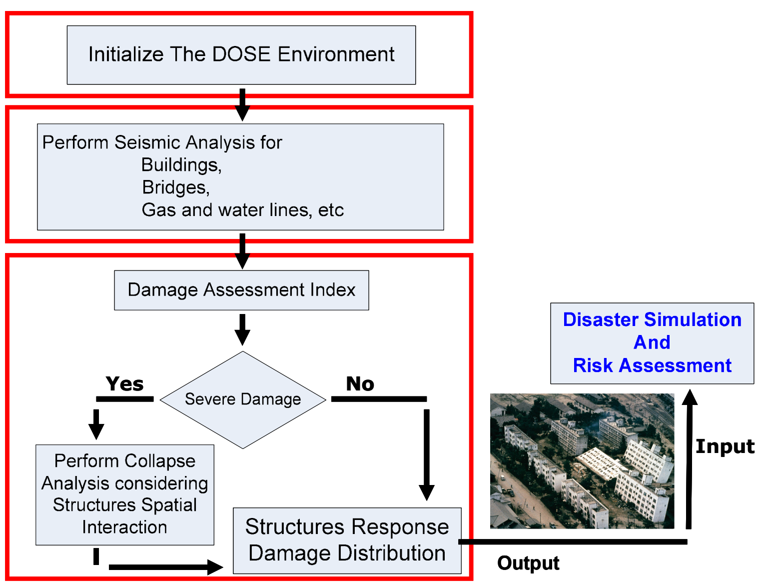

Figure 3: DOSE Environment Application for Earthquake Hazard Simulation

At this moment, however, GIS data which are open to the public have only limited data; available are basic data such as structure location and type or configuration data such as height and cross section. For residential houses and buildings, DOSE environment did use two numerical analysis services for a linear Multi-Degree-Of-Freedom (MDOF) system and a non-linear frame model. Methods have been developed for constructing these models from basic and configuration data stored in GIS, even though it is admitted that the constructed models have some ambiguity regarding material properties.

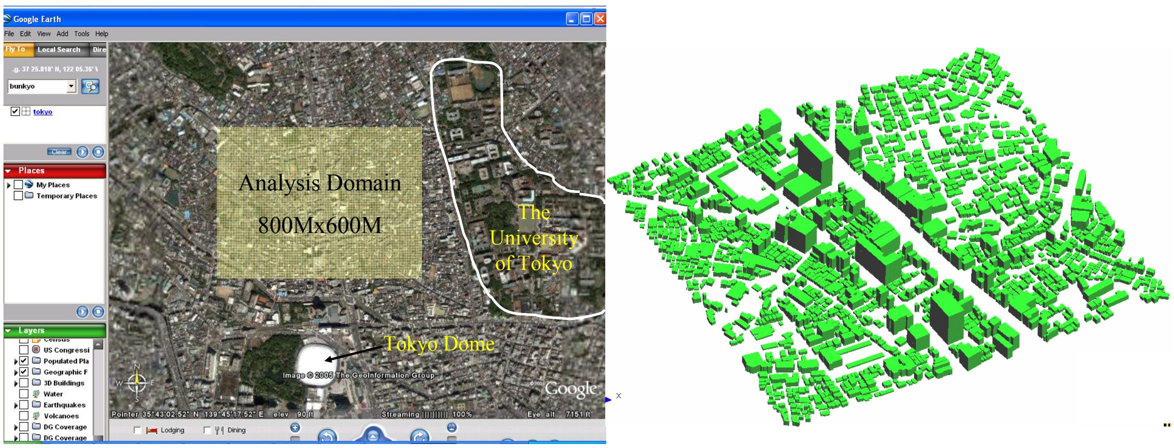

Figure 4: Analysis Domain Aerial view (left) and Digital image perespective (right)

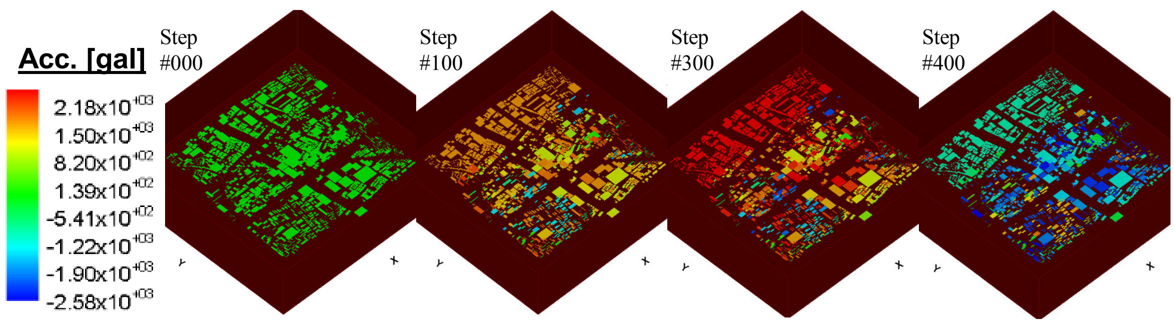

Figure 5: Spatial Variation in Ground Acceleartion Time History

First, linear MDOF system numerical analysis service has been used for conducting dynamic modal analysis for buildings. The resulted seismic response, absolute displacement [cm], for building structures has been introduced in Figure 6.

Second, Distinct-Element-Method (DEM) numerical analysis service developed by (Kiyono and Furukawa 2004) has been used to analyze dynamic response of RBSM (Rigid-Body-Spring Model) for residential buildings. Using GIS data, a building is modeled as a set of rectangular parallelepiped rigid bodies; columns, beams, slabs, roof, and a base. Each body has six degree-of-freedom and mass and moment of inertia are determined from its configuration. DEM implicitly solves the non-linear equation of motion for the RBSM. The resulted seismic response, collapse, has been introduced in Figure 7 in a plan-view, lines outside house boarders are collapsed elements.

The difference in building response at the same snapshot gives clear indication on the spatial variation of ground motion. It is qualitative evidence for the real non uniform buildings damage within the entire city. Indeed, such a locally complicated distribution of structure response is due to the fact that distribution is determined by complicated distribution of EGM and dynamic characteristics of each building. Locally complicated distribution of EGM and structure response is well expected by earthquake engineers who have observed non-uniform distribution of damaged structures.

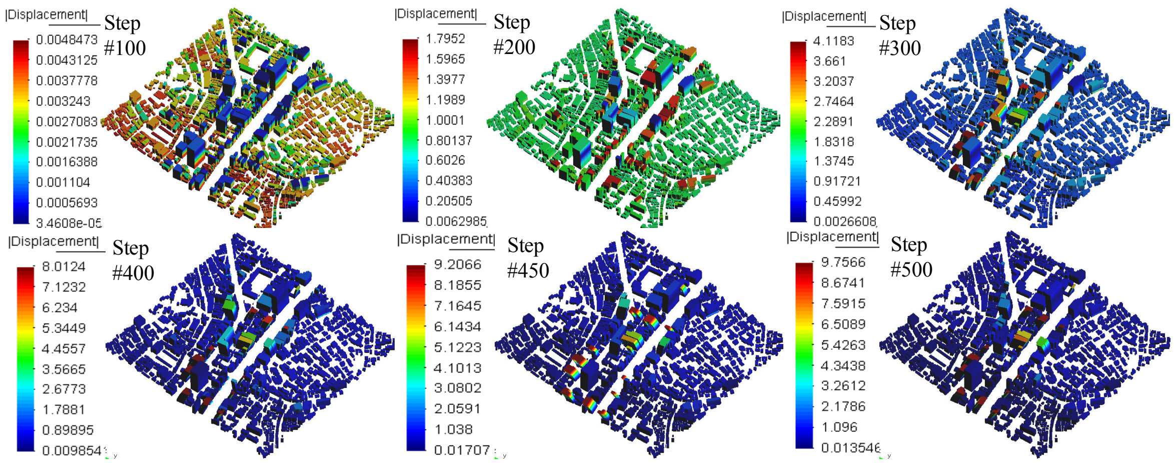

Figure 6: MDOF Analysis Response distribution in Bunkyo City

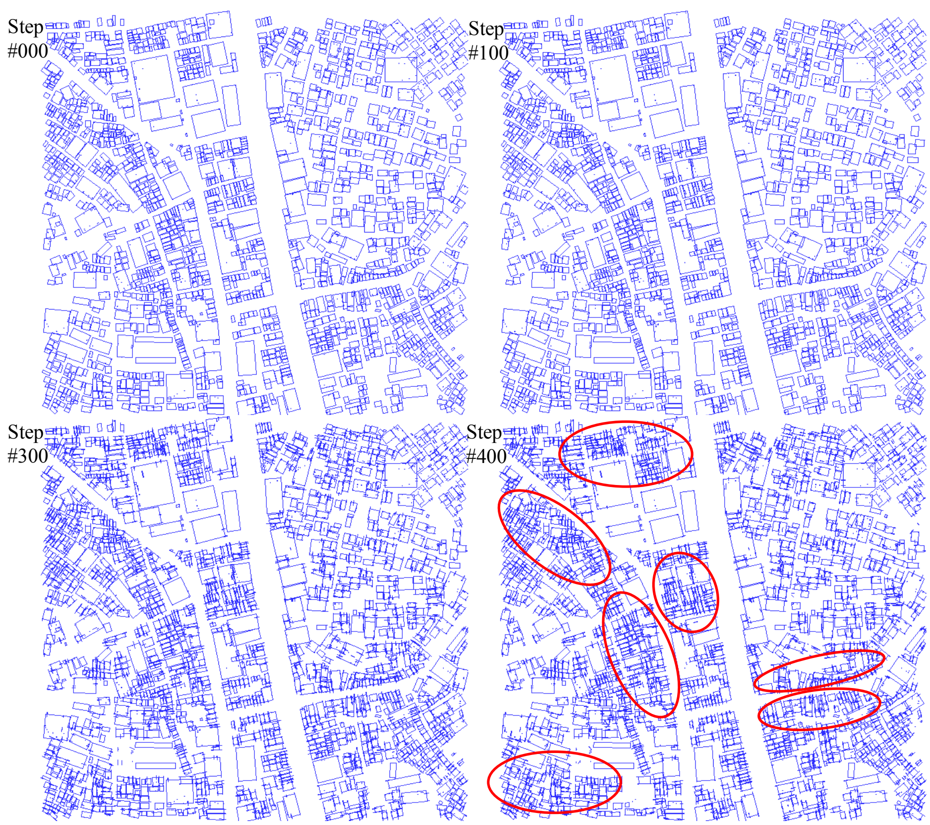

Figure 7: DEM Analysis Response distribution in Bunkyo City

CONCLUDING REMARKS

This paper explains the development of DOSE environment for urban systems integrated simulation under risk of urban-scale hazards. It simulates hazard scenario in a large scale domain, a complete city, throughout integrating hazard causes and effects. A Distributed Object-based architecture has been defined to set up environment concepts, constitution. DOSE environment architecture has been introduced with brief explanation for its interface layer. MPI technique enabled parallelized clusters, LAN, and WAN computations.

Numerical experiment results have shown the ability of DOSE environment simulation in detecting spatial variation of EGM and enabling each structure to receive its at-site EGM. This ability is obvious in the complicated distribution of buildings damage and the difference in building response within the entire city at the same snapshot. It is worthy to note that experiment results give an evidence for validity of environment architecture concepts which in turn afford feasibility of shaking large-scale domains in a Distributed Object-based Simulation Environment. Moreover, MDOF analysis and DEM analysis give an indication for scalability of DOSE environment and its capability to solve urban-scale interdisciplinary complex problems.

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