3D Visual Urban Simulation: Methods and Applications

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Abstract

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Computer advances in recent decades have contributed to the emergence of three dimensional (3D) urban simulation, which studies urban environments based on virtual models of physical reality. This article discusses methods of 3D urban simulation for urban planning and design in order to understand their potential, capabilities, limitations and concerns about the validity of simulation outcome. It also reviews the use of 3D urban simulation in many application categories including public participation, visual impact analysis, development control, dispute resolution and historic preservation. The authors observe dilemmas and suggest directions for better integration of 3D urban simulation into the planning practice.

주제어: 3D 시뮬레이션, 지리정보시스템, 시각화, 계획 적용

Key Words: 3D Simulation, GIS, Visualization, Planning Applications

Ⅰ. Introduction

Although simulation research has expanded rapidly over the past two decades along with advances in computer technology, simulation is not a new phenomenon. Simulation has been a research tool in several academic and practical fields for long time such as military and automobile industry as well as urban planning. Many urban planners have put efforts to replicate real world environments or activities in a way that the environment becomes more manageable and controllable, and such efforts have developed many simulation tools. One of predominant simulation among the many simulation tools that have been applied to urban planning is 3D urban simulation. Unlike 2D simulation which can be found in the literature (Al-Kodamany, 1999; Shiffer, 1992; Pinnel, et. al., 1999; Pinnel, et. al., 2000), 3D urban simulation refers to simulation with 3D objects representing current and/or proposed physical environment for research and decision-making.

While advanced computer technology allows applying 3D simulation to many planning projects, there have been limited concerns about the validity of 3D simulation technology. Although there are many concerns regarding the validity of simulation methods, three broad categories can be observed: accuracy, reality, and representativeness. For any simulation application, the following concerns are most fundamental regarding the validity of the simulation: how accurately does the simulation represent the real world environment, how realistically does the simulation replicate the real world, and what kind of information can be delivered through simulation.

The validity issues are strongly interrelated with the technology employed at each construction stage of 3D urban simulation. Any 3D urban simulation method typically involves three main construction steps: data collection, 3D modeling, and presentation. The wide range of simulation technologies mainly driven from the advances in computer technology can be categorized based on these construction steps. In the data collection step, the data necessary for building a replica of the physical reality is collected, for example, topography, building heights and dimensions. Such data can be collected from many different data resources and technologies such as maps, plans, video, Global Positioning System (GPS), digital aerial and terrestrial photos, satellite images and Light Detection and Ranging (LiDAR). The 3D modeling step refers to the process of creating a 3D replica based on the collected data. Depending on the technologies used for 3D modeling, the 3D replica can be constructed as a physical model or as a computer model. Finally, the presentation step, involves displaying the 3D model to the users. The user interface and the type of information delivered through the presentation can vary dramatically. Some wide spread technologies used for presentation include Geographic Information Systems (GIS), Virtual Reality (VR), Computer Aided Design (CAD), and multi media. A clear understanding of the features that each simulation technology possesses at each stage of the process will help urban planners be aware about what it may be achieved and what the limitations of each technology are.

This paper provides an overview of the wide spectrum of the 3D urban simulation technologies and their application in planning practice focusing in their capabilities and limitations. In the first part, a definition and a brief history of 3D urban simulation is provided followed by a discussion of different simulation methods and the concerns about their validity relative to the purpose of application in planning. Focusing on the relationship between the technologies and the validity of a simulation tool, this paper will describe how tightly these two issues are related together. In the second part, the paper reviews and discusses various 3D urban simulation applications in urban planning and urban design. Finally, the conclusions section provides a summary of the findings.

II. Evolution of 3D Urban Simulation

The discussion about the value of simulation research goes back to Aristotle, who valued the beneficial experience of viewing simulations of real life (Groat and Wang, 2002). This long history of simulation brings many definitions. Focusing on modeling a real world environment, Stokol (1993) defines simulation as the experimental modeling or representation of particular environments and events. Branch (1997) defines simulation for planning purpose as:

> "The simplified representation of an organism or activity as it exists or is visualized sufficiently inclusive and accurate provide a basis for analysis, decision, and action"

3D urban simulation in this paper is defined as simulation with physical representations of current and/or proposed environments and activities for research and decision making. Under these terms, this paper is focused in the visual simulation. The visual simulation is capable of showing a view of an object in perspective, the way we see real environment: with an impression of depth, as viewed from a particular position or viewpoint. Examples of visual simulations that are commonly used to portray urban applications include scale models, photo simulation, Computer Aided Design (CAD) graphics, and video simulation. In such simulation, a 3D model, either physical scale or computer-based, represents the real world environment and the variety of methods such as a 3D map, photography, photomontage, animations, and virtual reality are used for visualizing the 3D model. The unique advantage of a perspective view is that it places objects into a clear three dimensional relationship with other objects and with the surrounding context or setting (Sheppard, 1989). In addition to the visual interaction with virtual environment, advanced urban simulation allows to query a database for information on the buildings or areas a user comes across (Chan, Jepson, and Friedman, 1998).

As an effort to have realistic representations of the real world environment, researchers have used various simulation tools from relatively simple physical models to complex computer-generated models. Before having the advanced computer technology, researchers built physical models of urban environment in wood or styrofoam. Scale models, typically scaled from 1:200 to 1:500 represent architectural details and topographic features (Clipson, 1993). Urban Simulation Laboratory at the University of California-Berkeley puts efforts for reels. Before having environment in motion. The laboratory built physical models and simulated with camera lens for interaction with a physical model at bifocal view field of the human eyes (Bosselmann, 1993; Bosselmann, 1998).

As the computer technology developed, researchers tried to blend the computer power with physical simulation model, since the physical models still have several advantages such as low cost and maneuverability. One example of hybrid simulation tools is the Luminous Planning Table (LPT) developed at the Massachusetts Institute of Technology Media Lab and the School of Architecture and Planning. LPT is composed of projectors with cameras pointing down at their surface enabling it to see the changing positions of different physical objects placed on the table(Ben-Joseph and et al., 2001). Another example of a hybrid simulation tool was created by the Urban Simulations and Information Systems Laboratory at the University of Colorado (SIMLab). SIM Lab has developed a simulation tool with physical models representing a neighborhood and street views and a computerized neighborhood information system tool which was created and used in concert with the physical models to support neighborhood decision-making process.

The recent advances in computer technology have created new opportunities for the development of computer simulation applications. One of the early traditional computer technologies known as Computer Aided Design (CAD) originally designed for 2D drafting, has made rapid progress in the area of 3D computer modeling of the physical reality (Langendorf, 2001). A number of CAD programs not only support modeling of complex man-made objects, but also can be combined of multi media technologies such as computer rendering and animation. Virtual Reality (VR) is a simulation tool, which recently has been applied to urban planning. VR technologically has several limitations regarding building large urban models (Bourdakis, 1997). However, VR, which has been developed to Virtual Reality Modeling Language (VRML) and combined with the World Wide Web, allows a user being able to freely explore a model and view details from any angle, providing a very flexible way of interpreting any given model using a suitable browser (Smith, et al., 1998).

On the other hand, Geographic Information System (GIS) technology is capable of visualizing 3D digital terrain and can enhance the quality of visualization by draping aerial photography on top of the terrain. GIS also constructs a 3D scene of urban environment through extrusion with building footprints and elevation data (Langendorf, 2001). The most recent trend is the CAD/GIS convergence (Wilson, 1996; Langendorf, 2001). The desire that visualizes the relationship between the physical and other attribute evokes the data conversions between existing CAD and GIS software and encourages the development of new software bridging CAD and GIS.

III. Three Concerns in Urban Simulation

There have been numerous discussions about the use of 3D urban simulation as a tool for research and planning decision support. These discussions raise a number of questions about the validity and the features that 3D urban simulation tools should posses. Pietsch (2000) notes accuracy, reality, and abstraction as the tactical concerns of simulation, and Groat and Wang (2002) add cost and workability to the list. Sheppard (1989) reports representativeness, accuracy, visual clarity, interest, and legitimacy as the principles of visual simulation. When evaluating a vriety of visualization tools for public participation, Al-Kodmany (2002) lists the desirable attributes of these tools as interactivity, cost affordability, ability to represent complex contextual data, scale flexibility, capability to analyze potential designs, and ease of annotating the planning process. As seen above, although there are variations of concerns posed by a number of researchers, three common fundamental categories can be observed: accuracy, reality, and representativeness.

Those issues are also strongly interrelated with 3D model construction methods, types of 3D models used for simulation, and types of simulation tools and modeling methods. Table 1 illustrates the relationship between the methods chosen in each construction step of a simulation process and the validity concerns.

<Table 1> Relationship between production process and related technologies and validity issues

Production process of a simulation tool	Types of Technologies employed	Simulation validity issues
Data Collection	Data sources and collecting technology	Accuracy
⇩		
3D Modeling	Types of 3D models	Reality
⇩		
Presentation	Simulation tools	Representativeness

1. Accuracy and 3D Modeling Methods

The virtual world in a simulation environment must accurately reflect the real-world context as much as possible (Groat and Wang, 2002). In the other words, the accuracy of a 3D model used for simulation depends on correctness of the information utilized, modeled, and depicted. For both physical and computer-generated models, the accuracy depends primarily on the data sources during 3D modeling. Many resources are used to acquire 3D geospatial data. Data acquisition from maps, plans, video, Global Positioning System (GPS), digital aerial and terrestrial photos, satellite images and reports is also critical for the quality of the 3D model, as well as the data fusion process, where data and information is extracted from different data sources in order to build the 3D data model (Letourneau, 2001).

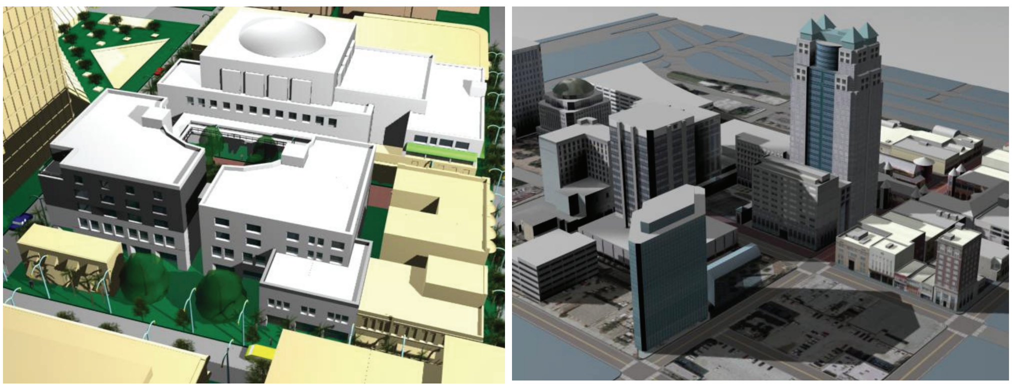
Although there are many resources available, most of resources are not appropriate for building a large urban model. Aerial photographs and LiDAR (Light Detection And Ranging) technology are the data that are most frequently used for building 3D urban models, are (Brenner, 1999). Photogrammetry is a technology that extracts features/geometries from aerial photographs. Images may be processed to facilitate the extraction of edges or homogenous regions. There edges are subsequently combine using geometric or perceptual rules in order to complete the object description (Smith, 2003). Using photogrammetry, the science of measurements on controlled photos; it is possible to create mathematically, a 3D model of any number of features visible on two aerial photos forming a stereoscopic pair (Limp and Cothren, 2003). Aerial photographs have been and continue to be the predominant data source for building reconstruction because the range of aerial photographs has become richer and affordable. LiDAR refers to laser scanning systems that send out a laser beam and measure the time it takes to return. If the horizontal and vertical angles of the beam are also accurately known, then an object's 3D location can be easily computed (Limp and Cothren, 2003). LiDAR may be used to rapidly create relatively large 3D models at a low cost, and even during unfavorable weather conditions.

The accuracy of each data mostly depends on the resolution of each data. Although various resolutions of aerial photos are commercially available, the resolution of aerial photographs that are generally used for 3D modeling purposes is six inches. Unlike aerial photos, accurate extraction of features still suffers from the limited lateral resolution of LiDAR, which is often one meter (Alharthy and Bethel,2002).Itisworthtomentiontheaccuracyissuerelatedwithlaborworks.Since photogrammetry or LiDAR has no fully automated way, which extracts geometries from images, a certain level of manual works must be required. For this reason the accuracy of 3D model also depends upon the level of skill and experiences of people who works for.

2. Reality and Types of 3D Models

Reality is the degree to which simulation represents the details of the real world. The goal of a simulation tool is to produce a high level of realism in the presentation of the environment (Bosselmann, 1993). A user should respond to the simulated experience in much the same way as he or she would to the real-world experience. The issue of reality is directly connected to the types of 3D models, which are used in a simulation environment in order to represent the real world environment. Since a user interacts with a 3D model under simulated environment, the reality of the simulation tool depends on the reality of the model. 3D models in simulated environments can be categorized into three types, volumetric, image-based rendering, and hybrid (Batty et. al., 2001).

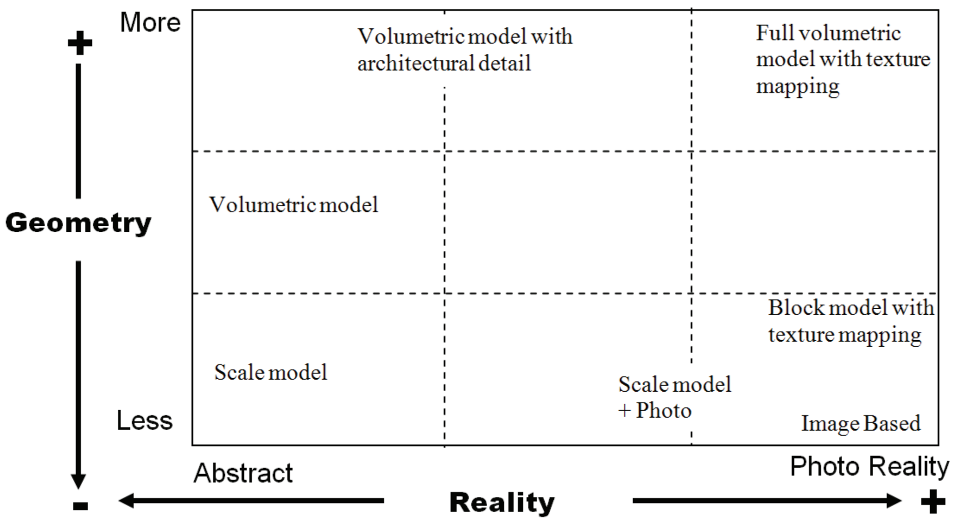
A volumetric model is a model with 3D geometries of individual buildings. CAD models and physical scale models belong in this category. The complexity of such models ranges from the full architectural details to the simplified geometries. A full architectural model illustrates the architectural details of a building with only geometries, and simplified models range from a building block model representing a building with boxes to a model with roof details adding shapes of a roof on the top of a box shape. Image based rendering refers to panoramic image-based modeling (Shiode, 2001). Image based rendering techniques attempt to extend the use of image data by warping images to enable production of viewpoints of the object. One of the most advanced examples of such models is Massachusetts Institute of Technology (MIT) City Scanning Project (Batty, et. al., 2001). Although this model is an inexpensive solution for pseudo 3D visualization, this model has no 3D geometries and no 3D depth in its viewpoints. The third 3D model type combines 3D geometries with images. In order to increase the reality of 3D models, some researchers used a new technique called texture mapping which refers to draping digital photographs on the computer generated geometries. With the texture mapping technique, the geometries in simulation environment becomes much simpler, but the level of reality is dramatically increased (Figure 1).



Volumetric Model　　Texture Mapped Model

<Figure 1> Types of Computer generated 3D models

The amount of geometrical detail has a strong relationship with another important issue, dynamic visualization. As the amount of geometries increases, the file size of the 3D model increases as well. As a consequence, the capacity of the hardware and software handling the simulation should be expanded, too. For example, a full volumetric model can achieve a realistic view, but the cost and requirement for computer hardware would be prohibitively expensive for a full city scale model. The amount of geometrical details does not necessarily reflect how much reality the model can actually offer; in fact, rapid and inexpensive modeling techniques such as texture mapping and panoramic capturing prove to be successful with the generic audience (Leavitt, 1999). An appropriate 3D model should be chosen based on the purposes of a project. Level of reality and accuracy should be considered. Figure 2 summarize the types of 3D models and their level of reality.



<Figure 2> Reality and Types of 3D models

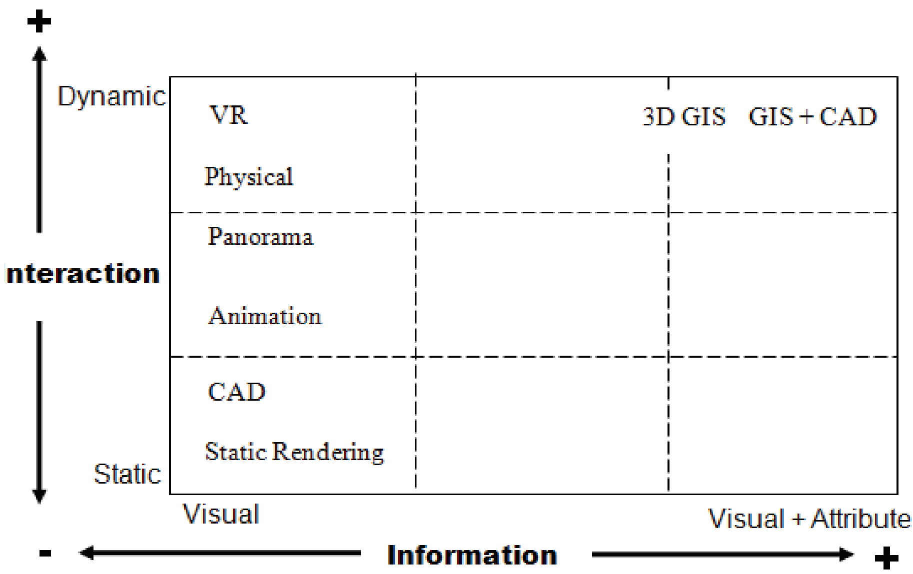
3. Representativeness and Simulation Media

Representativeness refers to the degree to which a simulation tool represents important and typical views of projects (Sheppard, 1989). Representativeness is related to the amount and the type of data that simulation presents as well as to the user interface of the simulation tool. Thus, the representativeness depends on a simulation tool, which displays a 3D model to a user.

A physical scale model provides direct interaction to a user. A user is able to observe and move around the model. However, the scale models lack human eyelevel simulation. To overcome this limitation, Urban Simulation Laboratory at the University of California-Berkeley has simulated street level experience with a camera lens and a scale model (Bosselmann, 1998). Since then, many affordable digital multi-media tools have been developed and applied to create computer generated 3D models (Langendorf, 2001). Computer generated 3D models are typically presented as rendered images, photomontage of rendered images with real world photographs, and animations. These multimedia methods still lack user interaction although they can represent views of the model from any viewpoint. Even the most dynamic method, computer animation, displays a predefined series of images. However, a new type of multi-media tool, called 360-degree panorama, offers a more flexible yet limited level of interaction. The 360-degree panorama allows a static viewer to interactively see the computer modeled 3D surrounding environment by changing the view target inside a 360 degree circle.

The advantage of this method over animation is the user-controlled interaction. However the viewer location is static and this method lacks free movement of the observer in the environment. A more advanced method called Virtual Reality (VR) provides a fully interactive simulation environment. Users can experience the simulated environment through walking, driving, or flying. VR, which it tightly integrated with the Internet, can be widely and easily distributed to multiple end users through World Wide Web and free browsers. However, VR applications have a fairy clearly defined upper limit of amount of geometry they can handle successfully which is quite low and unsuitable for urban scale modeling (Bourdakis, 2001).

While the tools listed above present only visual data, GIS applications visualize the 3D models and provide spatial data analysis capability as well. With the development of advanced commercial GIS software packages, GIS technology is able to drape and display an aerial photo on surface models such as a digital elevation model (DEM) or a triangle irregular network (TIN) model. Latest GIS packages also provide a simulation environment with a prismatic building model by building foot print extrusion. Transforming 2D GIS data into a 3D version entailed attributing third-dimension values to each spatial feature, using data on the number of floors for buildings; the result is simply a 3D visualization of existing essentially 2D data (Day and Radford, 1998). However, prismatic models lack any significant architectural detail and high level detail of roof morphology, thus do not convey any compelling sense of the environment (Batty, et. al., 2001). In order to overcome such a limitation, the recent efforts focus on bringing computer-generated 3D models to the GIS platform. Batty et. al. (1999) lists efforts on linking desktop or net-based CAD 3D models of cities to data stored within a GIS. However, the move towards bridging CAD and GIS in standard packages has been rather haphazard, with the 3D often only used as a substitute for basic CAD-like visualization (Hudson-Smith and Evans, 2003). Figure 3 illustrates the relationship between simulation technologies and the information delivered by them.



<Figure 3>. Representativeness and Simulation Technologies

IV. Applications of 3D visual simulation in urban planning and design

Simulation technologies in general have been applied to various planning application areas. In environmental planning, for instance, simulation has been used to simulate shoreline changes as well as geology and coal tar contamination caused by a manufactured gas plant (Day and Radford 1998; Adams Business Media, 2001). The applications discussed in this paper cover specifically the 3D urban simulation aspects of the broader simulation applications to planning which range from public participation to historic preservation, from visual impact analysis to urban environmental studies.

1. Public participation

3D simulation has been used as a communication tool in public meetings to facilitate public participation in planning and design development review. 3D simulation technology is reported to help the public in order to better understand planning and design proposals. In turn, the public can provide provide better feedback that leads to better decision making. Hardie (1988) and Lawrence (1993) have reported simulation with physical models for public participation. In Mochudi, Botswana, Hardie used a simple physical scale model for discovering from the residents their preferences about the street pattern of the new planned settlement areas. Bulmer (2001) reported two cases, Westwood Village and Visage project, which utilize simulation with computer-generated models. In the case of Westwood Village, the Urban Simulation Team (UST) at University of California Los Angeles (UCLA) built a virtual database of a proposed Westwood Village mixed-use development, and used the virtual model to communicate the proposal a community meetingal s a result of this consensus-building meeting, the local community was able to give valuable input to the design and was also alleviated of certain concerns they may have had. Visage project have given planners ability to unleash the full potential of their CAD models, without having to invest in expensive computing equipment. They can demonstrate to their community the impact of their building in life-like visualizations and animations. Kim (2004) statistically proves the values of real-time 3D GIS simulation in public meetings for the town visioning process of High Springs, Florida. Applying real-time simulation with photo-realistic 3D GIS data to public participation process for a town visioning project he compared the information delivery capabilities of 3D GIS data to conventional 2D presentation, and concludes that the 3D data helps the public have better understanding on the future changes of the town.

2. Visual impact analysis

Visual impact analysis is another area that has found wide use for the application of 3D simulation technology in planning and urban design. 3D simulation can facilitate the selection from several design options by creating a simulation environment in which the proposed alternatives are placed in the surrounding context and compared to each other. In his book, Representation of Places, Bosselmann (1998) described his involvement in 1982 midtown planning controls of New York City. He simulated potential development plans in the Times Square with a physical scale model made of cardboard with building façade photos. He also presented eyelevel views by taking photos of the model using a conventional 35mm camera with a close-focus lens. Hall (1993) reported three different cases, from a small-scale project such as a house extension (East Cambridge Case and Danbury Case) to a large-scale project such as redevelopment of a leisure complex (Guildford Case),that he simulated each development proposal with CAD models and a photomontage techniqueto visualize the future impacts of the developments. Levy (1995) also reported a case of the Geneva city that used a CAD model for visualizing a new lakefront development. The 3D model of the proposed lakefront development, which is placed within the context of the model of the city, showed the impact of the proposal to the city the impact of the project on future development. With the help of the 3D model the city created comprehensive design guidelines for the development of its lakefront site. A group of Taiwanese researchers reported a case utilizing a CAD model and a variety of multimedia tools such as animations, rendered images, and photomontages for developing design concepts, design guidelines and design alternatives for the Eastern Gate Plaza redesign project, a historical and economical center of the city of Hsinchu (Bai and Liu, 1998).

3. Development control

Like the cases of visual impact analysis, simulation has been used for development control by visualizing the changes of physical environment in the future. According to Day (1994), 3D simulation helped the planning committee of the City of Bath to visualize the impact of new developments on long distance views. He modeled three different schemes of a development and put them in an existing CAD city model, and then visualized each scheme with images and animations. The views of the site were set up from precise locations on the other side of the valley for each of the proposed schemes, and the planning committee probed the schemes from the long distance. Another example of development control application is to use 3D modeling as a support tool for cities future development strategy. Levy (1995) reported that the town of Cochrane used a CAD model in order to control construction boom. For this purpose, a 3D model played a significant role in visualizing the planning vision, exploring the existing city plan, and creating a downtown development strategy. Richland County, South Carolina, developed an interactive virtual downtown model of the city of Columbia to support commercial development pre-construction assessment, building renovation visualization, and economic development (Fitzgerald, 2002). Arlington County, Virginia, has used a similar approach by constructing a computer 3D model of downtown Rosslyn for economic development and community development control (Toole, et al., 2000). In both cases the 3D models were enhanced with photo textures and brought the models to interactive simulation environment. Then they used the simulation for a variety of purposes that mostly encouraged city's economic development and provided guidelines for downtown development.

4. Time dependent phenomena

Next application is analysis of time dependent phenomena. 3D simulation was used to observe some changes through time such as a skyline iconography study, pattern of city growth, shadow study, and distribution of population density. This category can also include movement studies. The image of a city observed by a movement sequence can be studied, for example, a city's skyline and landform from a view of approach to the city. Decker (1993) built a CAD model of downtown Cincinnati and simulated such sequential changes with animations and images. The digital model of Kongens Nytorv, the central square in Copenhagen, has helped to illustrate the process of the transformation of the square (Steen, et al., 2001). The Kongens Nytorv model that represented the square in three different years, 1750, 1997, and 2000 was used to show the impact of the future plans compared to both present conditions and past transformations of the square. The model played also a role in advertising the new development plan by being displayed on the Internet.

5. Historic preservation

3D simulation has also been to historic preservation. State Historic Preservation Offices (SHPOs) of the State of Georgia applied 3D visual simulation for assessing the effects of a proposed construction on historical properties (Edwards, 1998). Using a virtual model of the proposed project in the historic city of Columbus, Georgia, SHPO was able to better understand the impacts of the new project on the surrounding context and argued for changes in overall building massing, geometry, materials, and colors. Another example is 3D model of the historical center of the town Telc in Czech Republic. The model was used to propose an optional procedure for measuring historical objects and especially for creating classified knowledge about Telc. This knowledge was gained through historical and architectural analysis in the form of an information system connected to the state coordinate system (Pavelka, 2002). The texture mapped CAD model is presented in the formats of vector output, rendering, animations, and VRML. Two Japanese researchers reported an efficient method to build a historical city model, which provides important information for studying history of city planning and architecture (Suzuki and Chikatsu, 2002). Utilizing a historical map, they recreated the virtual town center of Tsumago and compared it to the present town center. Their comparative analysis helped the town to make decisions about preservation of historical row houses in the area.

6. Dispute resolution

The 3D simulation tools can produce the most objective views possible of any development proposal in order to facilitate the resolution of various disputes. For the Eastern River Front project, Decker (1994) using rendered images and photomontage based on a CAD model helped the city government and citizens groups to facilitate disputes on the possible violation of sensitive view by the proposals, For the Cole Neighborhood project (Arias, 1996), a hybrid simulation tool that combined physical models and a computer-generated model was used to ultimately resolve the conflicts between neighbors by providing the necessary information to make informed decision, in order to strengthen their perception of issues and opportunities and fd us in problems in the priority areas. The city of Copenhagen. The ed a 3D model of the area where a new hotel, the Congress Hotel was proposed to be built and used the model to facilitate a dispute between the developers and the residents. By means of the model the city was able to generate as many perspectives as desired to show the project from many sides. This helped the users to obtain a much more accurate impression of the size of the project and its architectural relationship with the surrounding cityscape (Steen, et al., 2001).

7. Environmental study

3D simulation can be successfully used for analyzing microclimate in an urban environment. Especially in downtown areas with high-raise buildings, issues such as wind tunnels, humidity, sunlight, and temperature have a direct relationship with human comfort and activity level, which affect human's physiological well being. The Environmental Simulation Laboratory (ESL) recommended wind protection standards and wind tunnel testing consistent to the City of Toronto based on performing wind tunnel simulation using a physical model (Bosselman, 1998). ESL analyzed seasonal maps that found the exact location where wind and comfort measurements had been taken and then changed the model to show potential development. Then, measurements were repeated at identical locations on the model and analyzed. And what were the findings and how did simulation help?

V. Discussion

This review has described several simulation technologies and their application to many different aspects of urban planning. Those technologies are organized in a relationship with a fundamental validity of a simulation research. Based on this overview of simulation technologies and their applications, we have found several dilemmas that may prevent 3D urban simulation from being fully utilized in a planning process.

The first issue is the inconsequence of usage of a simulation tool. In most of cases, a development proposal or at most a neighborhood model has been built and used for only single project purpose, and then are never used again after the project has been done. Thus all the efforts to build such simulation tools are wasted after the project. In order to encourage to application of 3D urban simulation to more various planning fields, a simulation model should be designed, built and updated in a way that the model can be compatible with other models and be utilized to many different purpose along with a city's planning process.

From this perspective, the approach that UST at UCLA has pursued can be a predominant example. UST has built a photo realistic model of the entire Los Angeles basin, an area of several hundred square miles (Delaney, 2000). The model is stored in a database structure and designed in a way that improves user interaction links, which facilitate communication between the various systems, particularly the real-time query of a GIS database in the three-dimensional environment (Ligget and Jepson, 1995). The team's ultimate goal is to create collaborative decision-making tools for use in community environment. Thus, while the database can be updated and managed as a whole, a part of the database can be extracted from the original database for a certain project purpose such as visual impact analysis, 3D automobile navigation, emergency response management, and transit related application (Jepson and Friedman, 1998).

Another issue is to utilize existing 3D urban models. According to Batty et. al. (2001), there are many computer generated 3D urban models driven by commercial and/or public sectors. Most of major cities in U.S. have a certain kind of 3D city models. The list goes from largest cities in U.S., New York, Los Angeles, and Chicago to other metropolis such as Portland, New Orleans, and Denver. For some of those major cities, multiple companies and research institutes have put their own and Denver. For s3D urban models. The list may be expanded every day. Compared with this number and Denver. models, the number and cases that utilize those models for planning purposes still remains in a handful number. Although many of those existing 3D urban models are developed by commercial purposes, it should be considered to pursue a collaborative work that guides those commercial efforts to planning fields. The last issue is to adapt latest 3D simulation technologies for urban planning. As the Table 2 shows, there is a gap between the technologies for development of 3D urban simulation and the applications of those technologies. In many of cases reviewed earlier, volumetric computer models and physical models are used for simulation although those types of models are less realistic compared with a photo-textured model. And as a simulation tool, multimedia seems to be used most frequently and create a trend although it has a critical limitation, limited interaction between a simulation tool and a user. Few simulation tools such as VR and CAD / GIS fusion which overcomes the limitation that multimedia has have introduced, but those simulation tools have not actively applied to planning fields.

VI. Conclusion

3D urban simulation provides a virtual environment that a user can interact with an urban space as it currently exists, as it existed ten years ago, or as it might look in the future after physical changes are made. The latest simulation technology goes further, and allows a user to remove existing building and to replacing them with new developments so that the user can observe the impacts or changes from the development. Due to the unique advantages of 3D urban simulation, 3D urban simulation has been used to solve several urban planning issues for the last decades. Several urban planners and researchers have applied 3D urban simulation to attract more community residents to public meetings, to foretaste environmental changes caused by future developments, to control urban sprawl, to analyze trends of a city's skyline and landform changes, to build a database of a city's historic buildings, to facilitate disputes related with new developments, and to study micro climate and wind tunnels of a city. Along with such active applications, 3D urban simulation technologies have been dramatically improved from simulation with a physical scale model to simulation with a photo realistic computer generated urban model. Although these advanced technologies have improved the capabilities of 3D urban simulation, there are still fractures between new simulation technologies and their applications. Many simulation tools are developed and used in a project base, so that they are dumped after the project. Although many existing 3D urban models are available, they are not actively utilized for urban planning purposes. And latest simulation technologies are limitedly applied to urban planning. In order to overcome such problems, it may be worth to build a large-scale database including a 3D urban model and attribute data. In the cases of UST at UCLA and City of Bath that have developed a citywide scale of 3D urban model, a 3D model of any community or neighborhood in the cities can be extracted from the cities' data, and simulated with various simulation tools for any kinds of planning purposes. As a whole database, the 3D urban data can be managed, updated, and reused along with the cities' planning process. Although building a city wide 3D urban model causes cost and labor, the latest advance in computer hardware makes the cost lower and user-friendly software interface reduces the labor.

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