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Environmental Simulations : Their Use, Appraisal, and a Research Agenda

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환경시뮬레이션의 이용과 평가, 그리고 연구과제

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요 약

제안된 설계나 계획이 미래의 환경에 가져올 영향을 예측하고 분석하는 도구로서 시뮬레이션은 환경정책의 수립에 있어서 중요한 역할을 한다. 오래 전부터 다양한 환경시뮬레이션 기법들이 고안되어 널리 사용되어오고 있으며, 더욱 효과적인 방법을 개발하려는 노력이 계속되고 있다. 본 논문에서는 이러한 환경시뮬레이션의 이용과 평가에 관련된 각종 이론들을 문헌조사를 통하여 개괄적으로 검토하였다.

본 연구를 통하여 시뮬레이션이 환경설계 및 계획과정에 있어서 작업의 효율을 향상시키는 필수적 역할을 수행하고 있음이 파악되며, 환경시뮬레이션의 보다 적절한 사용을 위하여 각 시뮬레이션 기법의 기능 및 기술적 측면의 평가와 인간지각적 측면의 평가, 그리고 시뮬레이션을 적용하려는 프로젝트의 성격에 관한 면밀한 조사등이 요구된다. 아울러, 본 분야의 미래 연구를 위한 연구과제들이 제시된다.

I. Introduction

The endeavors of environmental design, planning, and management are concerned with the manipulation of the physical environment. Assessing the potential environmental impact due to a proposed design or plan is therefore an essential step for decision-making in these endeavors. As useful tools for such impact assessment, a number of different simulation methods have been developed and implemented. The question, "How good is environmental simulation? (Bosselmann and Craik, 1987; Craik and Feimer, 1986)," has always been central to their use and has generated a complex set of research questions.

This paper outlines the current status of the environmental simulation field and its underlying issues through a literature review. The scope of this paper is, therefore, limited to the discussion of rather general theories and concepts in the field than dealing with specific data. First, a variety of environmental simulations will be discussed followed by review of their role in the environmental planning and design process, and the issues surrounding their validity and effectiveness. Finally, a future research agenda is proposed.

II. Types of simulations and their applications

1. Dimensions of environmental simulation

Accoding to McKechnie (1977), the family of techniques used primarily for replicating – i. e. previewing or anticipation – in the laboratory everyday environments that have not yet been built, modified, or otherwise actualized are known collectively as ***environmental simulations***. However, the term "simulation" is occasionally used for the representation of environments which currently exist. In this case, "simulation" is distinguished from "surrogate" (Taylor et al., 1987). A surrogate is a substitute for a real environment (such as a photograph); but a simulation is an analogue – i.e. something that is similar to but not really representative – of an actual environment (such as a scale model).

McKechnie (1977) provides a sueful typology (Figure 1) for classifying environmental simulations based upon dimensions of conceptual-perceptual and static-dynamic. The conceptual-perceptual dimension refers to the degree to which the simulation portrays the environment as abstract – simplified or symbolized – forms, or concrete forms with details. The static-dynamic dimension represents the degree to which the simulation offers single perspectives of the environment, or changing multiple-perspective views sequentially (Craik and Feimer, 1986).

	Conceptual	Perceptual
Static	*Static-Conceptual*	*Static-Perceptual*
	SIMULATIONS	
Dynamic	*Dynamic-Conceptual*	*Dynamic-Perceptual*

Figure 1. A typology of environmental simulations (McKechnie, 1977).

Following McKechnie's taxonomy, static-conceptual simulation includes functional diagrams, maps, and working drawings; static-perceptual simulation includes sketches, photographs, scale models, and computer renderings : dynamic-conceptual simulation includes radar, computer modeling of ecological processes, and gaming techniques used in urban planning; and dynamic-perceptual simulation includes filmed modelscope tours of scale models, video, and computer animations. As Zube et al. (1987) stated, McKechnie's typology thus suggests that the domain of environmental simulation is substantially suitable for landscape design and planning.

In addition, Craik and Feimer (1986) extends McKechnie's taxonomy for environmental simulations with a third dimension – scale. Particularly for physical models and photographic simuiations, scale can strongly bias the perception of simulated image.

2. Varieties of environmental simulations[1)]

A wide array of environmental simulation methods are used in contemporary research and design and planning projects. These include : plans, diagrams, elevations, perspective sketches, renderings, modified photographs (photo renderings and photomontages), slide projections, scale models, movies, videotapes, and computer graphics.

A review of the history of environmental simulation (Zube et al., 1987) shows that models are among the oldest of simulation techniques used to display construction tec-

註 1) There could be many different modes in environmental simulation – e.g. visual, auditory, olfactory, etc. However, the term "environmental simulation" in this paper primarily refers to the visual mode only.

hniques and three-dimensional relationships. They reported that the earliest examples of model simulations have been found in Egyptian and early Chinese tombs dating from about 2500 B.C.

The most widely used simulation techniques in practice are renderings—e.g. perspective sketches and paintings. Renderings provide the greatest flexibility in portraying different conditions, although they have limitations in changing views and rendering styles. The use of "hinged" renderings by Sir Humphry Repton in his "Redbooks" suggested a useful way of comparing existing landscapes and proposed changes by designs. This method was more effective than maps or plans to help clients visualize the changed future landscape (Zube et al., 1987).

The invention of photography brought a new medium for simulation. The photo-related simulations primarily include photomontage and photomanipulation techniques. These techniques share the same basic concepts with rendering simulations—e.g. simulating proposed landscapes by manipulating existing images, and comparing "before" and "after" conditions. However, they tend to be more objective than renderings because they use photographic images for the bass of simulations and there could be less opportunities for so-called "artistic expressions."

Scale model simulations have greatly advanced with uses of film and video. As a representative facility for these simulations, the Environmental Simulation Laboratory (Figure 2, 3, and 4) at the University of California, Berkeley offers exciting "walk-through" or "drive-through" experiences of scale models which range from urban to regional scale. In this facility, a camera which is controlled and guided by a computer moves through scale models of the environment and projects continuous eye-level views. Simultaneously, these views are recorded on color films and video tapes for future presentation (Appleyard and Craik, 1974). Other simulation laboratories are operating in countries such as Holland, New Zealand and Sweden. The Lund Institute of Technology in Sweden served as a model to Berkeley's Environmental simulator (Janssens and Kuller, 1986).

Computer graphics simulations (Figure 5, 6, and 7), including two-dimensional drafting and painting, and three-dimensional wire frame, surface & solid modeling, and animation techniques, promise to be a useful technique for simulation and visual assessment in future environmental research and practice. Particularly, three-dimensional models are more complex to implement than two-dimensional ones but can produce more accurate and realistic perspective drawings, with hidden surface removal, surface color and texture, shading, and shadow castings. They have not been frequently applied to open space or natural environment problems because of the difficulties in depicting irregular, natural shapes—e.g. tree branches and leaves, rocks, topography, etc. However, a recent report of the Simulation Laboratory at the University of Toronto's Center for Landscape Research (Danahy and Wright, 1988) shows a successful application of advanced computer simulation technologies such as three-dimensional, solid modeling, colored, and dynamic functions.

On the other hand, the recent integration of computer technology with a video imaging system (Orland, 1987; Orland, 1988) provided a useful simulation technique. This so-called "computer image processing" technique (Figure 8), which was developed originally for military surveillance, space exploration, and geographic information systems (GIS), is now recognized as a powerful and easily used tool

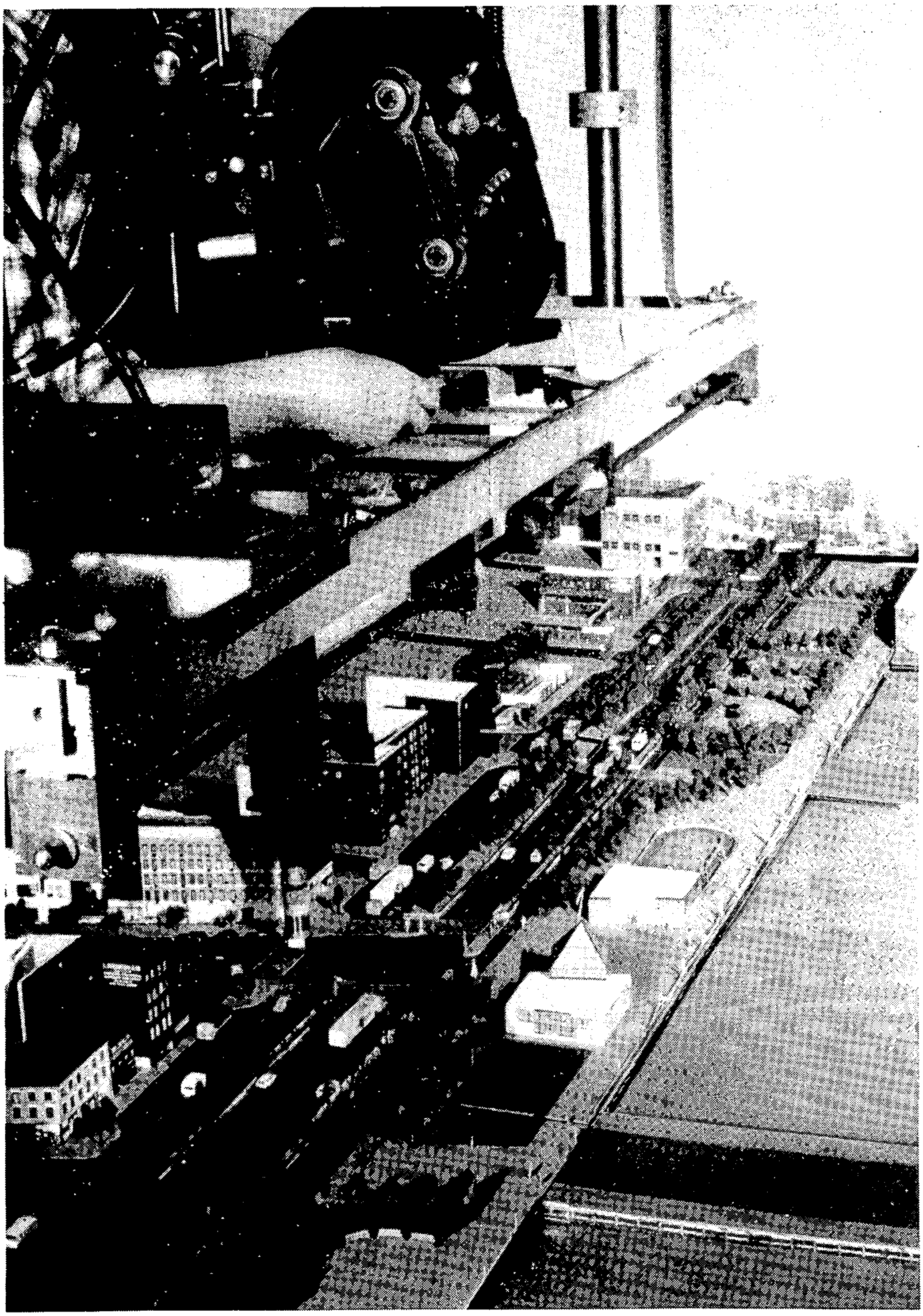

Figure 2. Film-recording of a "drive-through" simulation using a scale-model—the new west-side highway, New York, NY (The Environmental Simulation Laboratory, University of California, Berkeley).

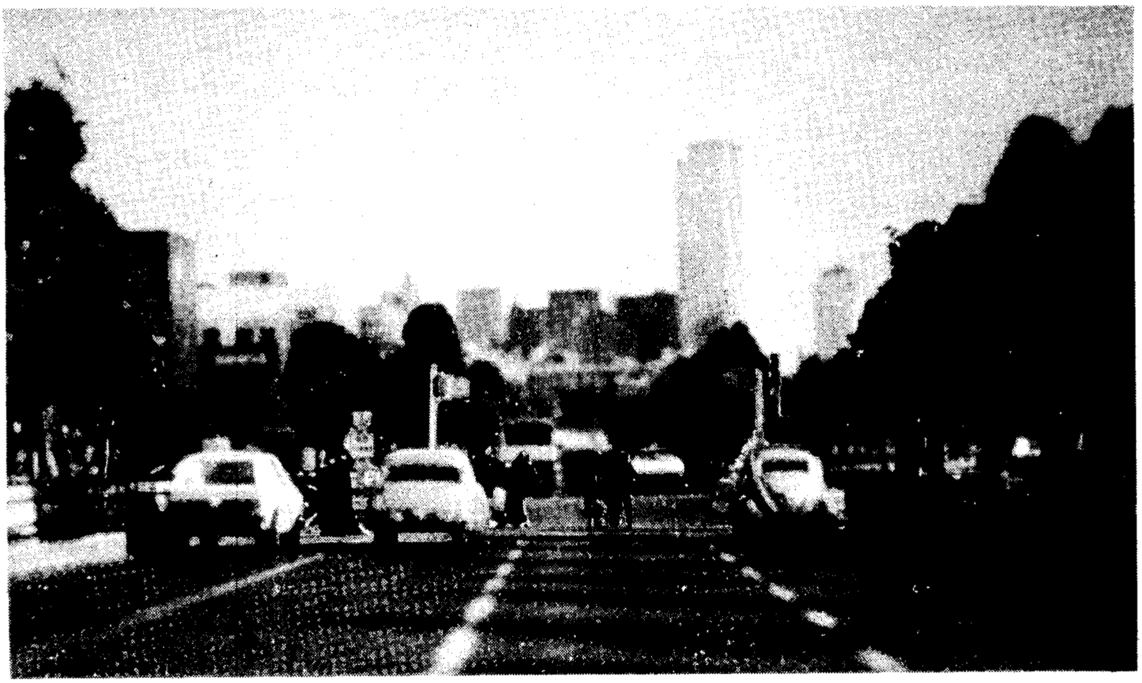

Figure 3. A simulated driving experience from Figure 2 (The Environmental Simulation Laboratory, University of California, Berkeley).

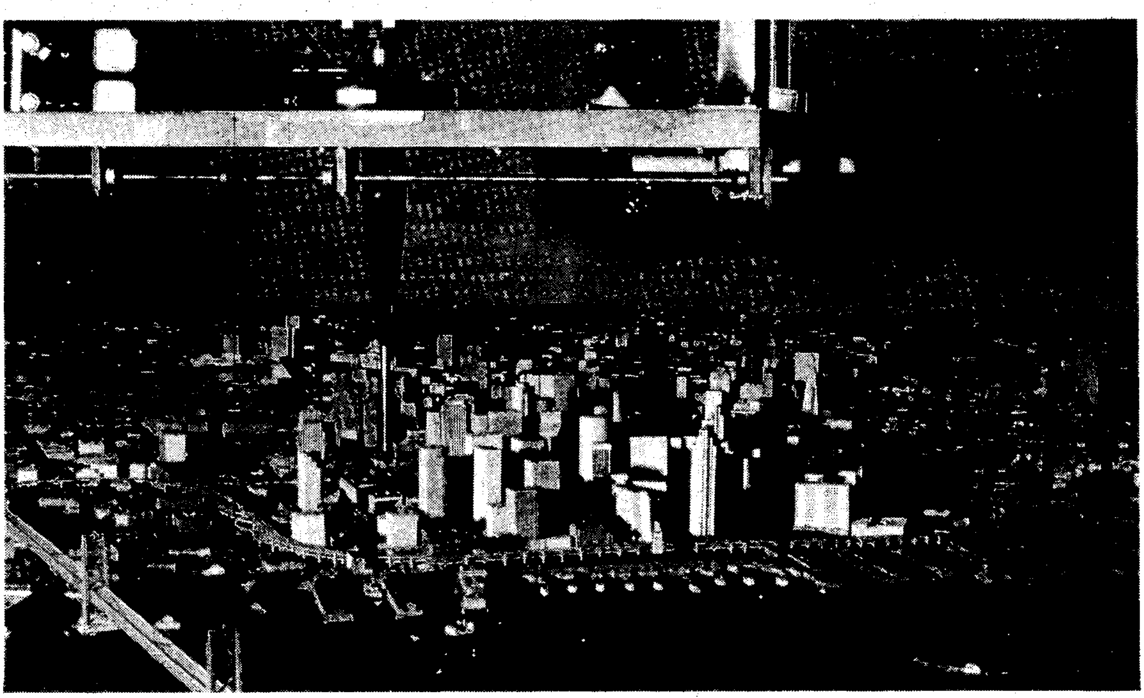

Figure 4. The city-wide scale model of San Francisco (The Environmental Simulation Laboratory, University of California, Berkeley).

to display near photographic quality environmental images. The major advantage of this technique over others is that it can assign realistic textures to the simulated objects through a "texture-mapping" procedure. Combined with the photographed contextual background, these texture-mapped objects produce a very credible simulation. Because this method basically shares the same concept as the photographic simulation technique, simulation speed and quality can also be greatly enhanced as the user (the simulation preparer) is familiarized with the technique. However, there is a drawback which the perspective projection and relative scales of simulated obj-

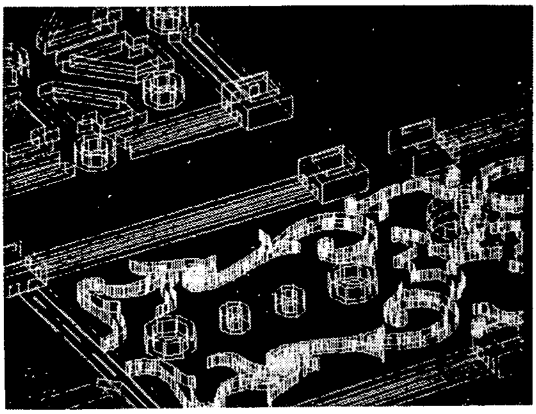

Figure 5. Wire frame computer simulation of a portion of Villa Lante garden.

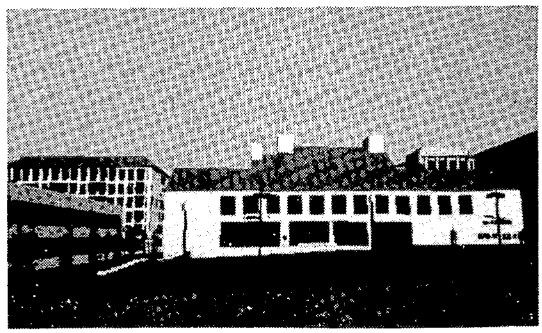

Figure 6. Surface model computer simulation of a campus building/ landscaping project.

Figure 7. Equipment for computer simulation—a personal computer and an advanced workstation with diverse computer graphics software (The Environmental Simulation Laboratory, University of California, Berkeley).

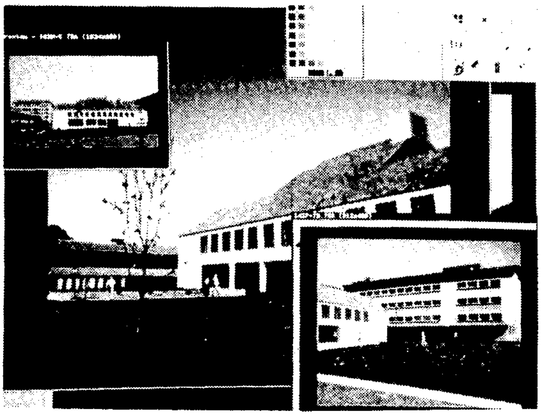

Figure 8. Image processing computer simulation on a SUN workstation with multi-tasking windows.

ects are often inaccurate by eye measurement.

On the horizon is the use of highly realistic computer generated animation. Combined with "ray-tracing" and "texture-mapping" techniques, computer animations can provide more realistic "walk-through" or "drive-through" experiences. The Program of Computer Graphics at Cornell University (Greenberg, 1988) has reported the application of these techniques to architectural design projects. However, there is a major drawback of the highly realistic computer animation technique in that it usually requires a complicated preparing procedure, and a enormous amount of memory space and a very fast processing speed in order to achieve acceptable image resolution and sequence. Due to economic reasons of this kind, less elaborated but still effective animation methods—such as those simplifying details, textures, or lights—are more commonly used in current practice.

Diverse computer graphics systems are used for different types of simulations. In terms of hardware, due to financial constraints, micro- or supermicro-level computer hardware systems are more popular in practice. The most popular microcomputers are IBM PC and Apple Macintosh; Sun, Apollo, Vax, InterGraph, and Iris systems are the most commonly used supermicro-level hardware. In terms of three-dimensional geometric modeling software, diverse systems are used for different purposes : Modelshop for a simple wire frame modeling; Auto CAD/Land CADD for more sephisticated wire frame modeling; Auto Shade and TOPAS for surface and solid modeling; and Computervision, GDS, and AES for various sophisticated modeling applications. In addition, imaging software such as TIPS operating on microcomputers and Artisan designed for supermicro-computers are widely used. All these systems have advantages and disadvantages and differ in regards to their functionality, economy, ease of learning/using, etc.[2] No. single system offers a complete capability. Therefore, cooperative combination of individual systems will provide ways in which higher-quality results can be achieved.

The recent development in simulation methods—particularly computer simulations—was possible by adopting more advanced technologies from diverse fields. This kinds of technological development, however, requires users of the methods to have at least a basic knowledge about operating simulation software and hardware. At the same time, a continuous update of the knowledge is crucial to cope with rapidly improving, so changing equipments.

註 2) The discussion of various systems using such criteria requires very specific in-situ evaluation, and is beyond the scope of this paper. However, this kind of functional and technical evaluation of computer simulation methods can be found in Oh(1991).

3. Applications of environmental simulation in research and practice

A wide range of projects with simulations in research and practice have been done for transmission lines, power plants, port facilities, mining, wind turbines, timber management, skihill development, highways, and large-scale buildings in urban settings (Sheppard, 1986).

Typical application of environmental simulation in these situations is mainly to show proposed places or projects to the general public at an environmental hearing. It may be used for the following purposes, for example ; (1) to illustrate basic planning issues such as zoning ordinances (Bosselmann and Gerdes, 1980); (2) to facilitate public participation in the early planning and design process that generates alternatives (Appleyard et al., 1979); (3) to communicate to the public new, untried possibilities such as the use of diverters and controllers in managing traffic in residential neighborhoods (Appleyard, 1981; Bosselmann and O'Hare, 1983); and (4) to examine land use compatibility judgements for projects systematically varied in descriptive attributes such as color, size, and texture (Wohlwill, 1978).

On the other hand, environmental simulation can be used for the presentation of selected places to participants in an environmental psychology research project. For example, through the comparison of "response equivalence (Craik, 1971; Sheppard, 1982a)" between professionals and the general public, the relationship between personality and the perception/cognition of physical environment can be investigated. Also, it can be used in urban design processes, for example : (1) to establish growth models of the urban core area; (2) to test sun-light and shadow castings over a short or long period of time; (3) to analyze wind flows and speeds between buildings and street corners.

III. Role of simulation in the environmental planning and design process

1. Advantages of simulation over direct experience of environments

There are three chief advantages of simulation over the direct experience of environmental settings : (1) it is more convenient to present complex environments without the need for transporting observers to the site; (2) it is possible to gauge responses of environments that do not yet exist; and (3) using simulation, there are greater opportunities for systematic, experimental manipulation of the environment and investigation of the impact of proposed physical features (Appleyard, 1977; Craik, 1983; Craik and Feimer, 1986; Feimer, 1984; McKechnie, 1977).

The importance of these factors lies largely in their potential for achieving economic efficiency in environmental design and for providing a better understanding of the nature of human-environment interaction (Craik and Feimer, 1986). For example, if the setting of interest is remote from observers and the setting is widely scattered, the time and expense to bring the observers to the setting becomes substantial. More importantly, proposed designs or plans for environments can be visualized before they are actually built, and can be presented to the public to elicit their positive or negative opinion toward the projects. This function of simulation can prevent unwanted results which may be costly. Finally, designer or planners can easily manipulate their ideas during initial stages. Particularly, using computer graphics simulations that can be quickly altered, they can analyze diverse impacts of proposed designs or plans—e.g. visual quality, visibility, and shade/shadow casting.

2. Role of simulation in the environmental planning and design process

According to Appleyard (1977), while simulations play a continuous role in the planning and design process, there are three crucial phases : (1) analysis of the existing environment; (2) design generation; and (3) presentation and public communication. In the first phase, the major task of the simulations is to extract relevant information to the design or the planning decision. In the second phase, the simulations must be more concrete and understandable. However, they should also be manipublatable in order to accommodate new ideas and information. In the final stage of presentation, the simulations should be realistic and comprehensible to the public.

More specific definitions for the role of simulations are provided by Sheppard (1986, 1989). Simulations are used : (1) as a design tool for designers and planners in the development of a project; (2) as an analytical tool for those reviewing the project (e.g. the project client, government agencies with regulatory powers, and third-party environmental consultants); (3) as a information device in presentations about the project to the public and interested parties; (4) as a stimulus for eliciting certain responses toward the project from public, key informants, and other groups; (5) as documentary evidence for environmental reports and legal testimony; and (6) as a tool for postconstruction evaluation and monitoring.

IV. Appraisals of environmental simulations

1. Criteria for "good" simulations

There are several criteria for "good" simulation methods. Appleyard (1977) suggests the following : (1) simulations should be realistic and accurate—they should convey how a project will be experienced by creating a "realistic" or life-like appearance; (2) simulations should be comprehensible and evaluatable—people of all educational levels should be able to understand and evaluate them based on their own concerns; (3) simulations should be engaging—they should not bore an audience so that they miss valuable information; (4) simulations should be cheap and flexible.

In addition to Appleyard's criteria, Sheppard (1986, 1989) suggests the following criteria : (1) simulations should be representative—they should depict project views and conditions which would prevail in reality; (2) simulations should be clear—their images should be clearly presented without loss of detail, contrast, or sharpness; (3) simulations should be bias-free—they should not mislead the user, and should elicit project evaluations which are as unbiased as possible; (4) simulations should be defensible—they should be legitimate by providing documentary evidence demonstrating how accuracy was achieved.

There are, however, difficulties in following the criteria outlined above in practice. There are so many unknown factors which can alter the original design or plan before the completion of the project (Sheppard, 1989). Unforeseen errors are often found in interim or even final simulations. Consequently, they delay the completion of simulations and increase costs of simulations.

It should also be kept in mind that all simulation methods are not equally useful to the users, and some simulation techniques are more appropriate than others depending upon the nature of the project. "Good" simulations for a project, therefore, should be decided through a careful and comprehensive analysis of the nature of the project. Based on the knowledge gained through this analysis, specific strategies for simulation can be established. Major items to be reviewed in this analysis are : (1) the project－design and planning objectives, scale of the project, detailed specifications for construction and landscaping, other data availability; (2) the site conditions－the site setting, visual quality and sensitivity of the site, daily or seasonal conditions, other data availability; and (3) the presentation format－the purpose of presentation, characteristics and size of viewers, and presentation media /methods. In addition, it is important to consider the skill and experience of the simulation preparer and the equipment requirements and avilability.

2. Issues in the appraisal of the validity and effectiveness of environmental simulations

A number of researchers have conducted experiments to test the validity and effectiveness of simulations. The study which provides the most comprehensive analysis of the principles and purposes of simulation is Appleyard's (1977) review of professional simulation media. He provides a "Communications Model of the Planning Review Process" which identifies the components and participants normally involved in project review. In the process, because the project proponents use particular media to present their proposal to a group of evaluators, predictive simulations usually play a key role. Since these participants hold different opinions of simulation validity and effectiveness according to their attitudes towards the project, Appleyard suggests objective criteria for evaluating simulations in his media-evaluation matrix (Figure 9).

One important aspect of this matrix is that it reflects functional aspects of simulations－e.g. texture, tone, color, three-dimensionality, and movement－as well as their psychological (perceptual) aspects－e.g. realism, accuracy, comprehensibility, and engagement. The matrix may never be filled, except in the most general way (Appleyard, 1977; Sheppard, 1989), but it summarizes different characteristics of simulations and offers an initial comparison of their effectiveness.

Craik (1971) suggests a "Process Model for the Assessment of Environmental Displays," where the critical test of validity is the similarity or equivalence between responses to simulations and responses to reality. This "ecological validity (McKechnie, 19777)" reflects the applicability of the results of the laboratory analogous to non-laboratory, real-life setting. This type of appraisal primarily examines the "human-environment" relationship with psychological approaches. The model identifies four sets of variables pertinent to the analysis of human responses to different environments : (1) characteristics of observers; (2) medium selected for presenting the settings; (3) the response formats used and the range of reactions they encompass; and (4) the environmental attributes of the settings (Bosselmann and Craik, 1987; Craik, 1968, 1971, 1981; Goodey, 1971; Pervin, 1978; Saarinen, 1969; Zube, 1974). Characteristics of observers may include such items as age, gender, environmental disposition (e.g. site-familiarity), and professional training (e.g. education in design and training in sim-

	Visual Replication										Criteria								Setting Appropriateness			
	Detail	Texture	Tone	Color	Viewfield	Viewpoints	3 Dimensionality	Movement (self-motion)	(animated)	Sound	Realism	Accuracy	Comprehensibility	Evaluation	Engagement	Initial Costs	Production Costs	Flexibility	Newspapers/ Questionnaires	Television	Public Hearing	Small group
Verbal Descriptions																						
Plans, Sections, Elevations																						
Aerial Perspectives Axonometrics																						
Ground Level Perspectives																						
Photo Montage																						
Perspective Sequences																						
Abstract Models																						
Naturalistic Models																						
Computer Graphics																						
Linear																						
Colored																						
Model Simulators																						
Slides																						
Video																						
Films																						

Figure 9. Media-evaluation matrix (Appleyard, 1977).

ulations). Presentation media include actual site-visits, photos, photoslides, scale models, sketches, and computer graphics. Response formats may employ such instruments as adjective checklists, the Scenic Beauty Estimate, cognitive mapping, and descriptive checklists/open-ended questionnaires. Finally, the attributes of the project settings include scale (e.g. small, medium, or large), and locus (e.g. urban, suburban, or natural).

Perception research appraising environmental simulations requires the specification of appropriate criterion measures. Although research in environmental perception and assessment has sought to identify a basic set of descriptive and evaluative measures, it has not yet produced a standard set of response formats (Craik, 1971; Feimer, 1984). Consequently, appraisals of perceptual simulation tend to employ lists of descriptive-evaluative adjectives that vary in content and length (Bosselmann and Craik, 1987). The use of bipolar descriptive-evaluative dimensions, often presented as a version of semantic differential ratings, has served as the sole response format in many investigations despite its well-known limitations[3] (Ward and Russell, 1981, Craik, 1981; Bosselmann and Craik, 1987; Sheppard, 1982b; Sheppard, 1986). The Environmental Adjectives Check List (EACL), and the Landscape Adjectives Check List (LACL), and the Regional Q-sort Deck (RQSD) which were developed by Craik (1975, 1983) are examples of the descriptive-evaluative dimensions.

V. Remaining issues and a future research agenda in environmental simulation research

More extensive use of environmental simulation in research and practice calls for "better" simulation methods. Because yet there is no single simulation method that can fulfill the users' needs completely, more efforts should be made on improving simulation technologies and ways of their application. The following agenda for the future environmental simulation research is, therefore, suggested.

1. To identify the level of abstraction of simulations to maximize effectivensess and minimize efforts

The emphasis of previous research on the appraisal of environmental simulations needs to be examined. Previous research has tended to focus on the issue of realism or accuracy of simulation. But the simulation does not, indeed cannot, reproduce that reality completely. Rather it selects critical aspects of that reality for the particular purposes at hand (Appleyard, 1977). For environmental planners and designers, representation of these critical aspects could improve the visualization of their schematic concepts or detailed design ideas. More significantly, in practice, the abstraction of detail is directly related to the savings of effort, time, and costs of simulation. (For example, generating a less sophisticated image using the computer may require a smaller memory space and a shorter processing time.) The more practical issue for environmental planners and designers may be : What degree of abstraction can be used while maintaining the effectiveness of simulation as a design tool? However, excessive abstractions often cause unwanted bias for the observers' perception of the simulated reality. Furthermore, this may be a problem for the clients or the public who generally have less ability to interpret and conceptualize the abstracted form (Appleyard, 1976), Although simulations are abstracted for any reasons, the reality should be sufficiently transmitted to the viewers. In order to pursue both economy and effectiveness in simulation, therefore, finding the appropriate level of abstraction of simulations is crucial.

2. To test performance of simulation media in facilitating the communication of ideas at different design stages

Another important issue is to investigate how observers perceive simulations at different environmental design stages. For example, what simulation medium best facilitates communicating the schematic and detail design at those stages? In the past, simulation was mainly used at the end of a design process as a fi-

註 3) Such as "Does response come from environment or verbal concept? (Bechtel, 1987)" For more description, see "nine problem areas of the semantic differential" which Bechtel(1987) pointed out.

nal presentation tool, and tended to confirm decisions already "cast-in-stone." The designer or the project reviewer, consequently, could not have opportunities for input and feedback of their new ideas, and a costly and irreparable design mistake could be resulted. However, as simulation techniques are advanced and are widely used in the field, they are more often applied to the mid or even the initial stage of the design process. If any particular simulation methods are found to be more effective than others at a certain stage, more efficient use of simulation could be achieved. Exploring the relationship between the effectiveness of simulation methods and the design or planning process will thus be a challenging research question.

3. To test performance of computer simulation techniques in portraying the environment compared to traditional simulations

Newly developed media such as computer graphic simulations should be explored. With their rapid technological development, computer graphics provide powerful features which can be effectively utilized in environmental simulation. However, as Zube et al. (1987) mentioned, the computer graphics techniques have not been critically evaluated as tools for environmental simulation, and the documentation of their effectiveness and validity is not available at present. A comparison of these techniques with traditional ones, therefore, should yield important results.

4. To link computer simulation techniques with the use of quographic information systems (GIS)

Most computer simulation methods discussed in this paper can be more effective when the data encoding procedure is linked with the use of geographic information systems (GIS). Because GIS has already been recognized as a useful tool to analyze the environment, a number of environmental design and planning projects today enter and process survey data electronically (using computers). The data entered here can be converted into different data formats, so that various CAD systems use them. while the survey data normally include both physical and nonphysical environmental information, the physical information—such as topography, vegetation, infrastructure, etc.—is initially useful for simulation purposes. For example, topographic data—i.e. usually two-dimensional information with x & y coordinates, sometimes three-dimensional information with z coordinates additionally—can be used for the simulation of terrain models. If there are new structures to be built, these structures can be simulated on very accurate locations and elevations. Likewise, simulations of vegetation and infrastructure can be done very accurately. This kind of integration of GIS into simulation procedure truly enhances the accuracy of simulations compared to the past, and still there is more room for this kind of technological improvement along with the future development of GIS.

5. To explore possibilities of combining different simulation media to increase the effectiveness

Special emphasis should be given to the effect of combining different types of midia. It is presumed that simulation media currently available differ in their advantages and drawbacks, and there is no one complete simulation medium which meets every user's needs. In order to get a simulation medium which better satisfies the user's needs, it is suggested to combine different simulation media. Combining two or more media can produce special effects which cannot be achieved by using any single simulation medium. For example, a simulation using photos or films can be combined with sketches, scale models, or even computer graphics technologies. Along with this kind of experimentation, the advantages/disadvantages or the capabilities/limitations of each combination can be compared. For practical use, however, the focus of evaluation should be on the degree of the trade-offs between competing values—such as realism vs. economy.

6. To test simulations with more complicated environmental settings to generalize the effectiveness of the simulations

In order to appraise a full range of capabilities of each simulation method, simulations should be tested with more complicated environmental settings which have both built components—e.g. buildings, infrastructure, or streetscapes—and natural components—e.g. topographic changes, water bodies, and vegetation. Because each simulation method differs in its effectiveness according to different attributes of environmental settings, it is critical to generalize the conditions of settings to compare several different methods.

7. To study the functional/ technical advantages and disadvantages of simulations

Very few studies regarding the appraisal of environmental simulations have attempted to document and analyze the functional/technical aspects of simulation. Because the selection of a certain medium in practice often depends upon its technical feasibility, it is critical for environmental planners and designers to have at least a fundamental knowledge of the technical aspects of simulation methods, such as required configurations, costs, and time. Also the difficulties in learning and using simulation methods are unknown. This situation suggests that more systematic and comprehensive research is necessary for this neglected agenda.

VI. Conclusion

It is certain that simulations will be more extensively used as critical tools to enhance the outcome of environmental design, planning, and management endeavors. Adopting more effective simulation methods, designers and planners can communicate their ideas to the actual users of the environment more effectively, and prevent potential environmental problems due to design or planning mistakes.

A number of simulation methods have proven to be effective, playing significant roles in diverse design and planning projects. However, all of them are not equally useful or no one single method can be used for every kind of project. Appraisals of functional/technical and perceptual aspects of simulations, as well as scrutiny of the nature of the project, will only provide useful guidelines for the selection of "good" simulation methods.

In relation to their use, appraisal, and technical development, several remaining issues discussed in this paper need to be resolved. In particular, more efforts should be made on the improvement of computer simulations which will lead the future environmental simulation technology.

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