Data Mapping, Modeling and Experiential Simulation as Information Management Tools in Urban System and Infrastructure Design

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Introduction

The purpose of this paper is to document and analyze available urban modeling and simulation technologies, some of which were introduced during the *ETH Information Architecture: Urban Simulation Workshop* entitled *Reconstruct the Future!* which was conducted during June 2009 in Zurich, Switzerland. This information is presented as a framework for the addition of future research and should not be considered an exhaustive list of available technologies. Instead it should serve the *Zofnass Program for Infrastructure Sustainability* and its team members as a tool by which to determine which, if any, technologies Zofnass Program should pursue in future research.

Background

The Harvard University Graduate School of Design (GSD) *Zofnass Program for Infrastructure Sustainability* is a research group funded by donors Paul and Joan Zofnass of the *The Environmental Financial Consulting Group* (EFCG) and supported by GSD faculty and students. The mission of the *Zofnass Program* is to support research and education that will result in the development, distribution, and adoption of sustainability standards for large scale development and infrastructure. The *Zofnass Program* aims to better enable the design industry to promote and utilize sustainable options for the design and delivery of infrastructure projects.

The *Zofnass Program* promotes the development, distribution and adoption of sustainable development methods and tools that define and quantify "sustainability" in the context of infrastructure and large-scale developments. The objective is to develop a set of recommended guidelines for developing sustainable large-scale projects. This will be accomplished by working in collaboration with the *Center for Environmental Health at the School of Public Health*, *Harvard's Office of Sustainability*, the *Harvard University Center for the Environment,* faculty at the GSD and other divisions of Harvard University that house sustainability expertise, and design industry leaders.

The primary goal of the Zofnass Program is to identify the issues and complete an "alpha" version of the recommended guidelines for sustainable large-scale projects. To achieve this goal, the Zofnass Program will study quantitative methods that can be used for measuring sustainability, as well as the integration of sustainability into the design of infrastructure and large-scale projects from the earliest stages of their

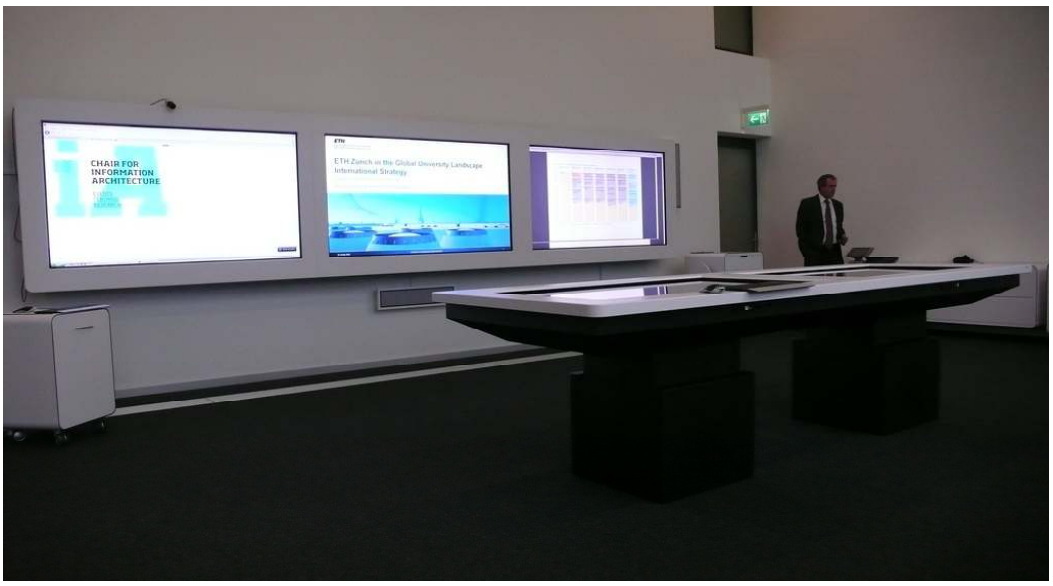
This case was prepared by research assistant Shelby Doyle, LEED AP under the supervision of Dr. Richard W. Jennings, FAIA, Lecturer in Architecture and Research Associate at the Harvard University Graduate School of Design as part of Zofnass Program for Infrastructure Sustainability, Prof. Spiro N. Pollais, Director, as the basis for class discussion rather than to illustrate effective or ineffective management of an administrative situation, a design process, or a design itself.

development. The Zofnass Program's applied research focuses on the management of information, the diffusion of innovation, and the economics of sustainability.[1]

In June 2009, the author attended the Swiss Federal Institute of Technology Zurich's (ETH) *Information Architecture: Urban Simulation Workshop* entitled *Reconstruct the Future!* (RTF). The RTF Course is part of the *International Alliance of Research Universities*[2] *(IARU) Global Summer Program* (GSP). GSP students have the opportunity to explore the most urgent challenges and opportunities for humanity in the 21st century. Issues explored by the IARU range from international environmental policy, contemporary Asian development to global leadership.

The RTF Course was presented by the *ETH Chair of Information Architecture*, which develops visual computer based methods for supporting analysis, design and planning of urban systems. The Chair for Information Architecture investigates innovative design and visualization methods in order to develop seamlessly interconnected computer-assisted design and simulation processes. Research goals of the Chair are the fundamentals of knowledge visualization and the integration of simulations. The Chair's educational and practice goal is the design and simulation of sustainable future cities.

The RTF Course provided an introduction to visualizing city schemes through computer-based methods and field trips within Switzerland to a variety of urban environments. The goal of the course was to familiarize the students with computer-assisted design processes and test its application within the field of architecture. A key part of the education at the Chair is the Value Lab, a new collaboration environment for virtual design and planning. It combines the use of complimentary views on high-resolution computer displays with direct multi-touch content manipulation creating a streamlined workflow for the evaluation of design. The Value Lab space currently consists of five large-scale, high-resolution LCD-panels and two high-resolution projectors. Three LCD-panels are wall mounted in an interactive display wall and two are combined to create a large interactive display table. Both the display row and the interactive table are equipped with multi-touch technology. [3]



ETH Chair for Information Value Lab

[1] Zofnass Program for Infrastructure Sustainability Website
http://www.gsd.harvard.edu/research/research_centers/zofnass/index.html
[2] The IARU is comprised of ten research universities: ANU, ETH Zurich, National University of Singapore, Peking University, University of California, Berkeley, University of Cambridge, University of Copenhagen, University of Oxford, the University of Tokyo and Yale University
[3] ETH Chair for Information Architecture Website http://www.ia.arch.ethz.ch/

Urban Simulation Overview

For the purpose of this paper the expansive field of simulation will be understood as the art or science of imitating the future based on the knowledge of the past and present. Additionally, a computer simulation will be understood as a system that is designed to simulate an abstract model of a particular system through the use of a mathematical model. This simulation method attempts to find analytical solutions to problems and thereby enable the prediction of the behavior of the system from a set of parameters and initial conditions. As Paul Waddell states in Introduction To Urban Simulation:

Design And Development Of Operational Models "While the value of theoretical models is facilitating a broad understanding of some underlying principles of urban development and transportation, much of this work remains too simplified in its assumptions and too abstract to be of direct value to agencies needing to inform decisions about specific policies and investments in particular urban settings." Waddell's paper also offers an excellent overview of Urban Simulation, see attached.

Specifically the topic at hand is the simulation of urban centers, their processes, and the infrastructure that supports these environments. Urban centers, or cities, represent the most complex human-constructed systems on the planet and therefore their simulation is particularly difficult to manage and control through computer modeling. A single author of an urban simulation cannot create a result similar to that which emerges from the millions of authors who contribute to the design city. What then can be done? Should the Zofnass Program pursue urban simulation as part of its processes and if so how should the group move forward given the current limitation of urban simulation technologies?

The question that arises from this initial assessment of urban simulation is: which factors should be considered in an urban simulation? The possible inputs are endless: material, water, capital, information, architecture, history, biology, geology, zoning, transit, memories etc. More importantly in the case of computer-based simulation, not all of these inputs are easily quantified or rather quantifiable in a useful way. For example, temperature is an easily available metric, which nonetheless offers several subjective analyses. The average temperature of a city is a data set that is often available for at least the last two centuries. However, during that time the technology which measured the temperature likely changed, the location of where the temperature was taken likely changed, the person who took the temperature likely changed and so on. Additionally, the temperature taken and recorded for a city is likely the numeric average of several temperature stations, for example New York City's temperature is defined in part by the temperature of Central Park and LaGuardia Airport, two very different environments.

For example, the number considered to represent the average temperature of New York City is really at best a generalized number assigned by humans to reflect the closest thing to an average which we are collectively capable of representing. For example, if I wanted to simulate the temperature fluctuation of East Fourth Street between Avenues A and B where I lived during 2004 and 2005 then I would be at a loss to represent the actual temperature of the street, not to mention the completely different temperature of the apartment courtyard, and the roof, which was often several degrees cooler. This isn't a useless anecdote about a singular event instead it in an analogy for all of the metrics which make up a city. Cites are constructed of millions upon millions of these extremely specific moments which are not easily quantifiable and which may or may not aggregate to create a different result than the averages which are general input into a computer model.

The act of simulating entails representing certain key characteristics or behaviors of a selected physical or abstract system. Since simulation always involves the placement of human constraints upon a system it can never be an entirely objective process. Rule-based mathematical models are flawed analogies for a city which is authored by millions of people, sometimes over hundreds of years, creating a number of inputs far exceeding current computational capacity. More importantly, humans and groups of humans do not follow a given set of rules with the consistency necessary for computational parameters to be applied.

The Zofnass Program aims to identify those metrics which are most useful in gauging the success of an urban environment. Consequently those metrics which are the most useful to simulate in the research and design phase of a projects are those which can be quantified and mathematically modeled. For the sake of research consistency acceptable metrics are those, which are derived from measurable data and factual information and can be used as a basis for reasoning, discussion, or calculation. For the purpose

of computer simulations this information is most valuable in a numerical form that can easily be digitally transmitted or processed.

Additionally, and perhaps even more importantly than establishing a metric and gathering that metrics is the communication or reception of knowledge or intelligence extracted from a data set. The mapping of information far exceeds a graphic exercise. Like simulation, the mapping of information is a subjective process. Each mapping and simulation software explored demonstrates strengths and weaknesses in the method by which data is represented.

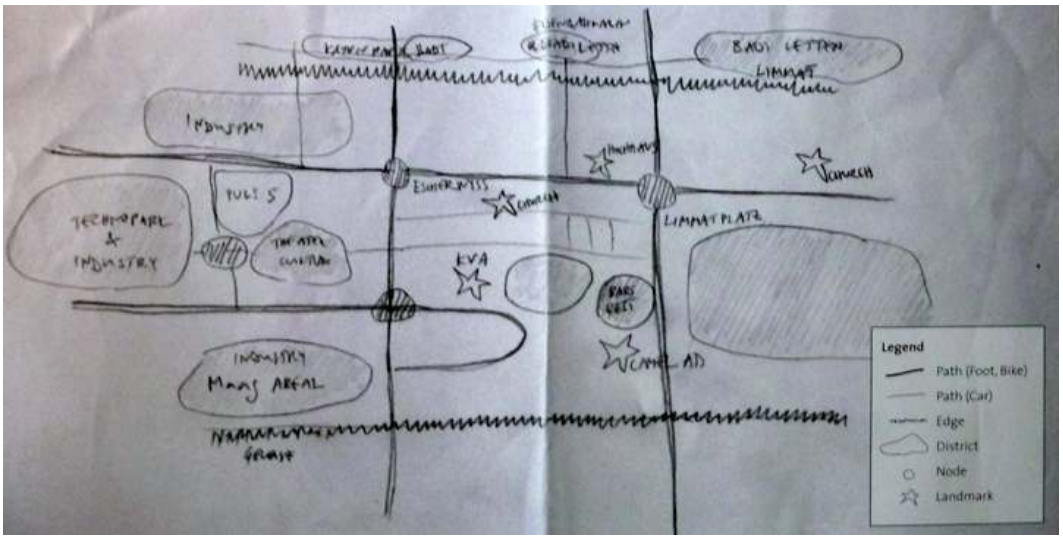
Mapping and Simulation Software Strategies

The following list of mapping and simulation software began during the *ETH Reconstruct the Future!* Workshop. Not all of the specific technologies were covered in the workshop but the general concepts behind the software and mapping strategies were discussed at length. The following technologies were chosen for their possible use to the Zofnass Program either in concept or practice. Some of these strategies are about how to accurately map a current condition. The idea behind these maps is that by building an accurate conception of the present a projection or simulation of the future becomes a possibility.

Mental Maps

Mental maps are a concept introduced to the RTF workshop by Dr. Remo Burkhard. These maps are individual conceptions of urban space and experience. Individuals physically document their mental conceptions of a space. This documentation may include perceptions of distance, quality of experience, mental placement of boundaries and nodes relative to one another and individual landmarks in urban space.

This is a highly subjective but often informative way of mapping space. In design this tool can be used at the schematic design phase. It is informal and 'inaccurate' as a metric but often very telling in which spaces people like and why. This type of mapping allows for collaboration with sociologists, psychologists, anthropologists and other researchers working to document human responses to space.

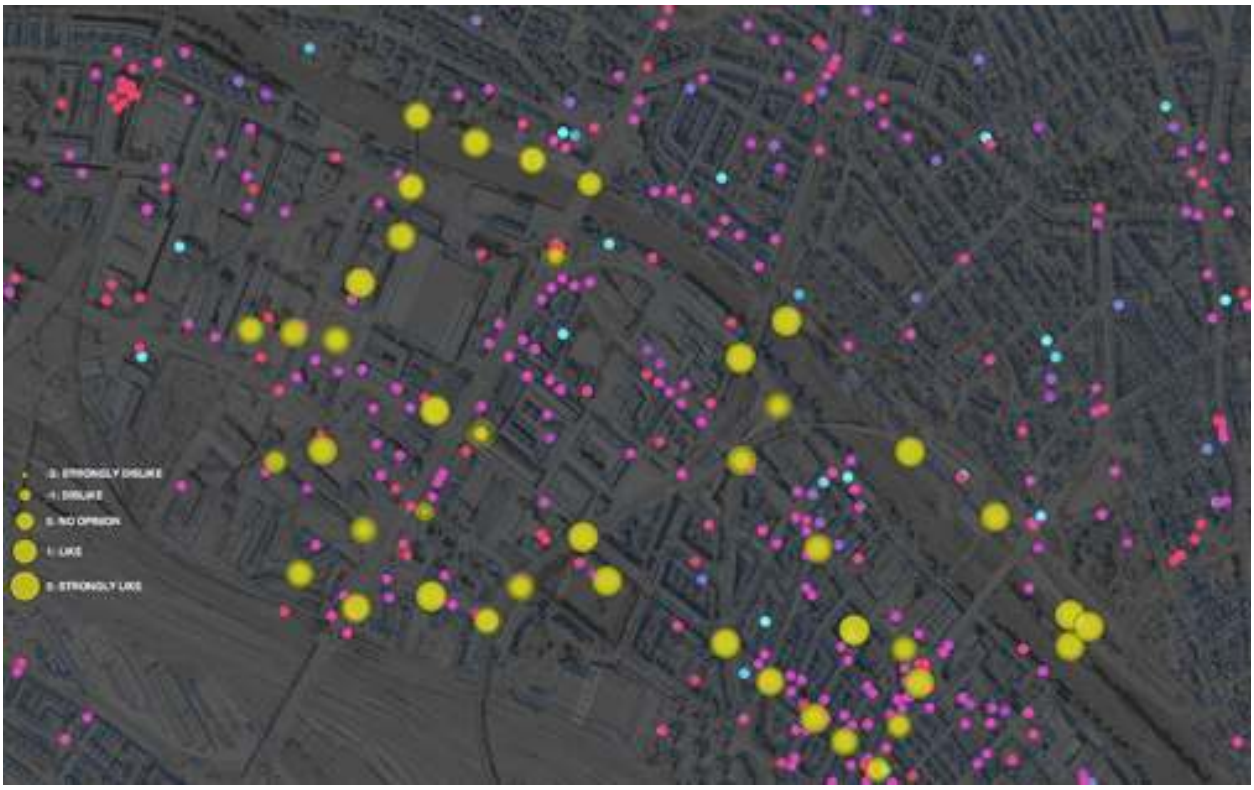


Top: Mental map from Dr. Remo Burkhard
Left: Google map of the same area in Zurich

Processing

Processing is an open source project initiated by Casey Reas and Benjamin Fry, both formerly of the Aesthetics and Computation Group at the MIT Media Lab. It is "a programming language and integrated development environment (IDE) built for the electronic arts and visual design communities", which aims to teach the basics of computer programming in a visual context, and to serve as the foundation for electronic sketchbooks. Large data sets can be managed and translated into visual maps or images through the use of Processing technology. This technology was introduced during the RTF workshop. Students mapped their fellows mental maps of forty three destination points to create an understanding of which urban spaces were ‘liked’ the most and why. This was measured by a ranking of -2 to +2 for each stop and a brief comment about each stop.

As a design tool processing allows for the visualization of data into information, which would not otherwise be understandable to a viewer. The nature of this visualization is highly subjective and dependent on the designers understanding of the data set and what the designer wants to convey to the viewer.



#name station-1 NUM station-1 WORDS station-2 NUM station-2 WORDS station-3 NUM station-3 WORDS...
kai 2 nice, massive infratstucture 1 jogging, sunny, clear water, river 1 view, water, water noises, windy 0 playground, petting-zoo, many people 2 nice bridge 0 cool bookshop / cafe 1 green, hot girls 0 no people, empty, nice building structure-1 big square, nice trees, no people -2 ugly paintings, terrible music 0 1 nice factory -1 loud, generic square, boring 0 infrastructure, construction 1 nice office -2 boring, non-space 1
nice station 2 mountain, demolishment 2 infrastructure, many people, busy 1
sweet freitag tower 2 cool arc\'s0 green 1 nice tectonics 1 nice park 1
coop, supermarket, nice little square -1 too clean 0 no trash 1 nice cafe\'s 1
very busy, urban 1 urban area 2 cool square, action, loud, busy, many people -2
weird, boring 0 -2 ugly architecture 2 interesting space 1
infrastructure, music 2 amazing river, urban 2 nature, water, river 2 great bridge, cool perspective 1 alternative people, beer, cafe 2 volleyball, beach, water, river, bikini 2
swimming, fun 1 many people, beer, exspensive

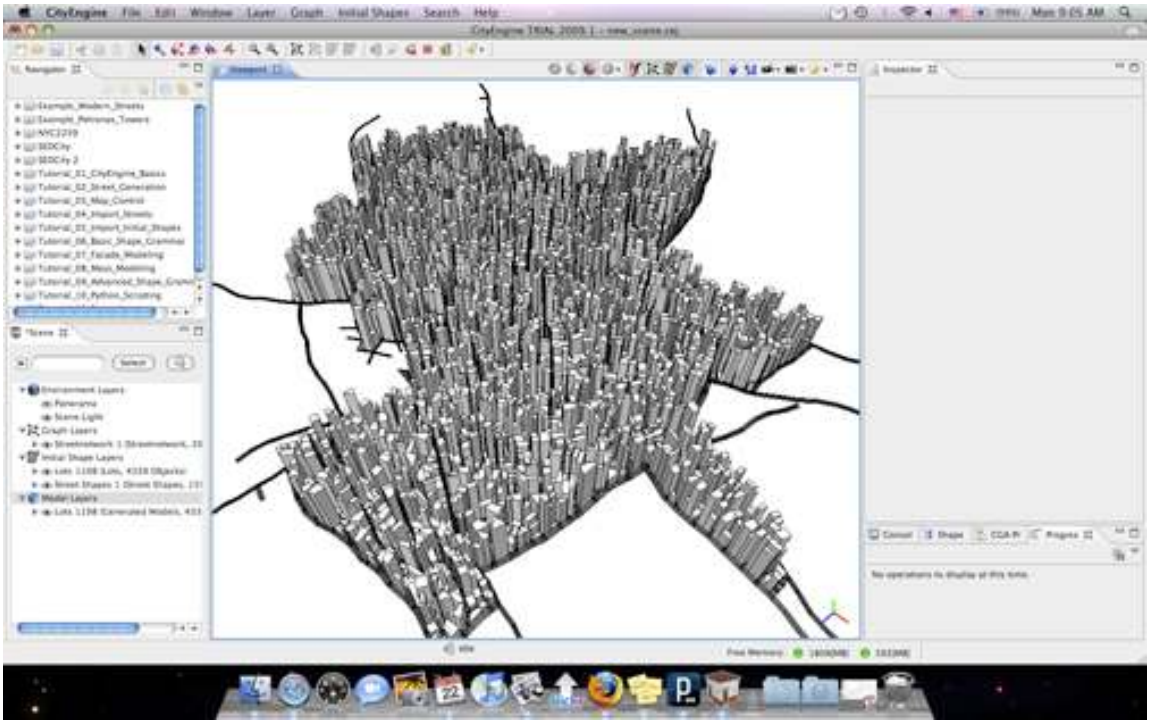
Top: Graphic representation of the same area Mental Mapped by Dr. Burkhard
Middle: Graphic and text representation of the same area Mental Mapped by Dr. Burkhard
Bottom: A sample of the raw data which is demonstrated graphically on the above two maps through Processing

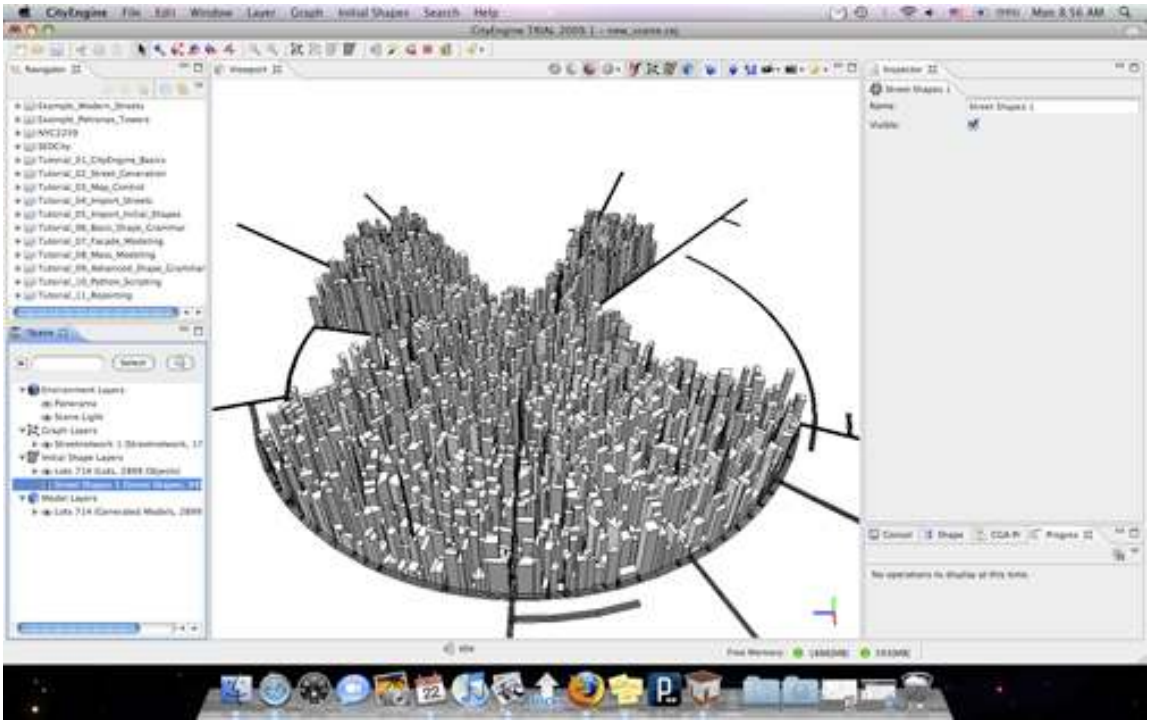
CityEngine

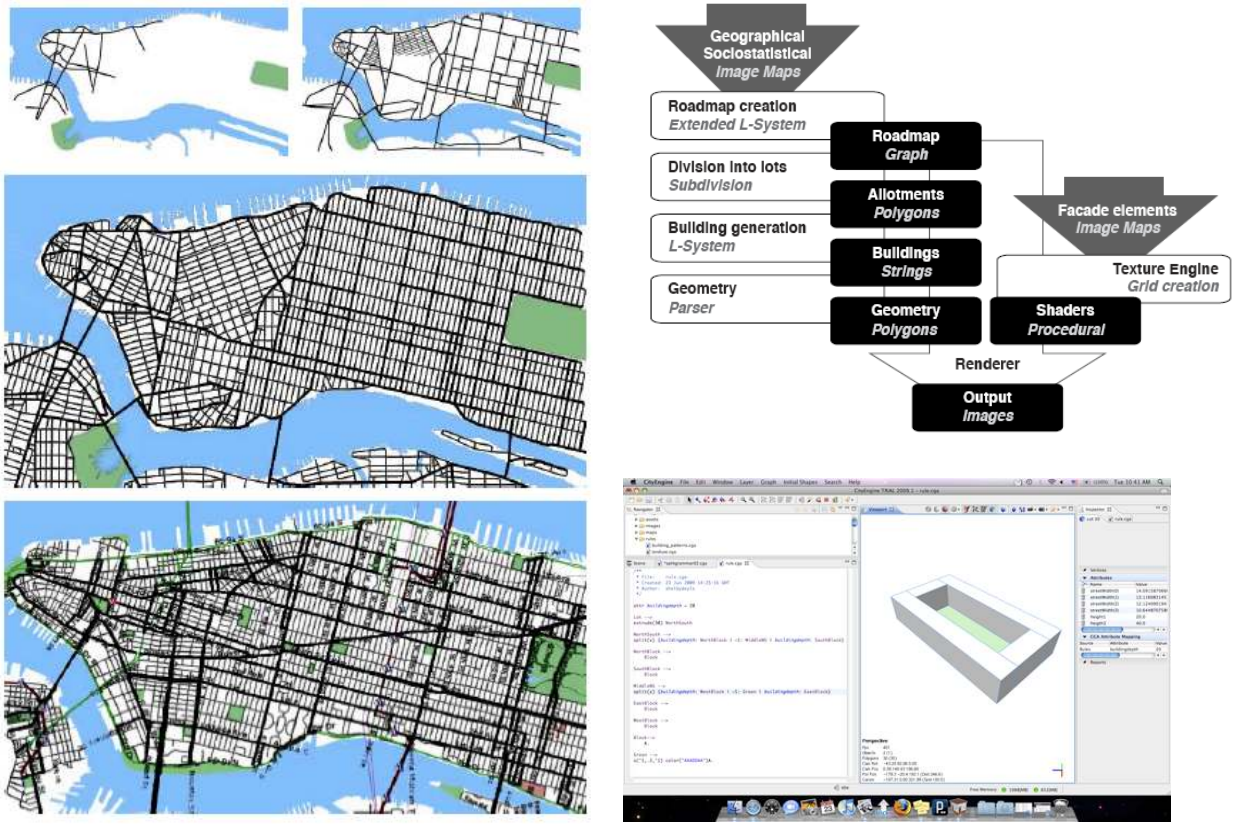
The CityEngine software provides professional users in entertainment, architecture, urban planning and general 3D content creation with a unique early design and modeling solution for the efficient vizualisation of urban 3D environments. CityEngine was developed by ETH graduates and introduced during the RTF workshop. The CityEngine offers unique street growth tools to quickly design and construct urban layouts. Street patterns such as grid, organic or circular are available and the topography of the terrain is taken into account. Real street networks of any city in the world can be imported from OpenStreetMap. This allows for a quick generation of existing urban surroundings. Furthermore street networks or lots designed in other programs can be imported via the DXF file format. Scripting of parametric buildings and 3D streets. CityEngine urban simulation technology uses rule-based scripts to rapidly generate types of cities. As can be seen in the below map of Manhattan, existing cities often have aspects of their grid

which break the rules. In the case of Manhattan Broadway does not follow the grid but plays an important role in the quality of the city. As the technology develops these mutations will become easier to manage.

As a design tool for rapid urban generation CityEngine is very useful. It is not accurate enough to be used as a simulation tool for an existing or future urban environment, although it is readily available and used in movie-making and video game development.





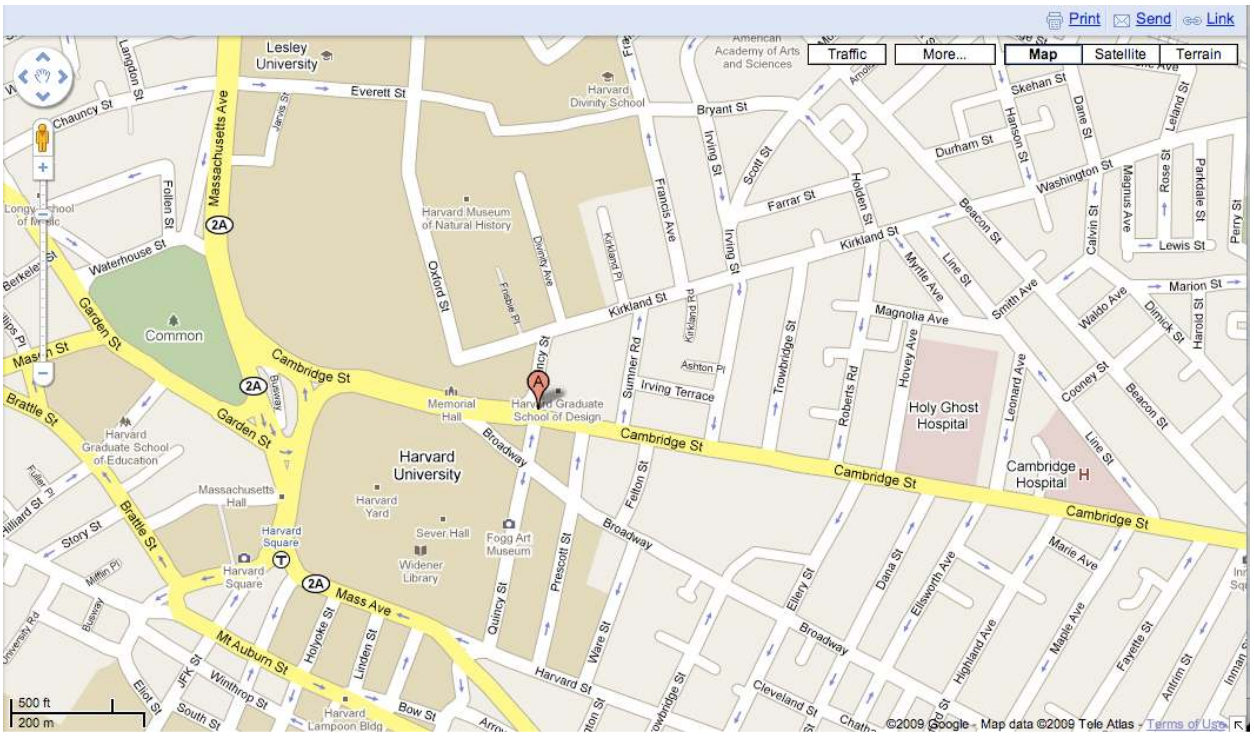


Top: Organic city generated with CityEngine. Middle: Radial city generated with CityEngine. Bottom Left: Rule generated “Manhattan” as compared to an actual map of Manhattan Bottom Right: Work flow chart for CityEngine Bottom Right Corner: Parametrically scripted 3D Building

Map

A Google Map is a satellite generated political boundary and road maps. Selective place names included at different scales or ‘zooms.’ The technology is free, easy to use and web based. Accuracy should be confirmed with a third party if possible when using Google Map as a research tool. During the workshop Google Maps were used to identify what looked to be ‘interesting’ spaces from an aerial view. The identified spaces were then visited and it was noted whether the original notion of ‘interestingness’ was accurate. Data is drawn from multiple sources to create these maps.

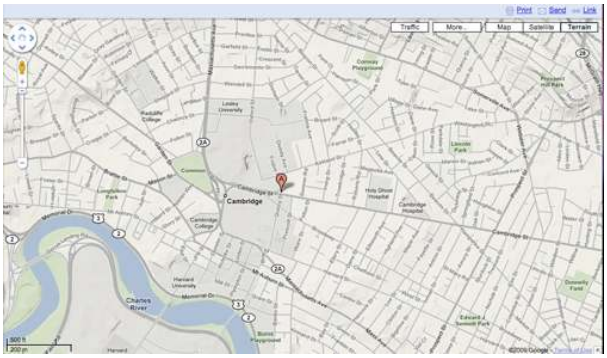
In design this birds eye view is often used at the urban planning scale to show how a new development could fit into an existing context. This type of mapping is a traditional design tool and can be a useful at any stage of the design process.

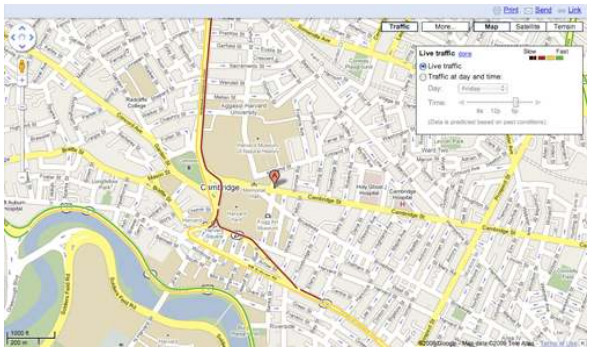


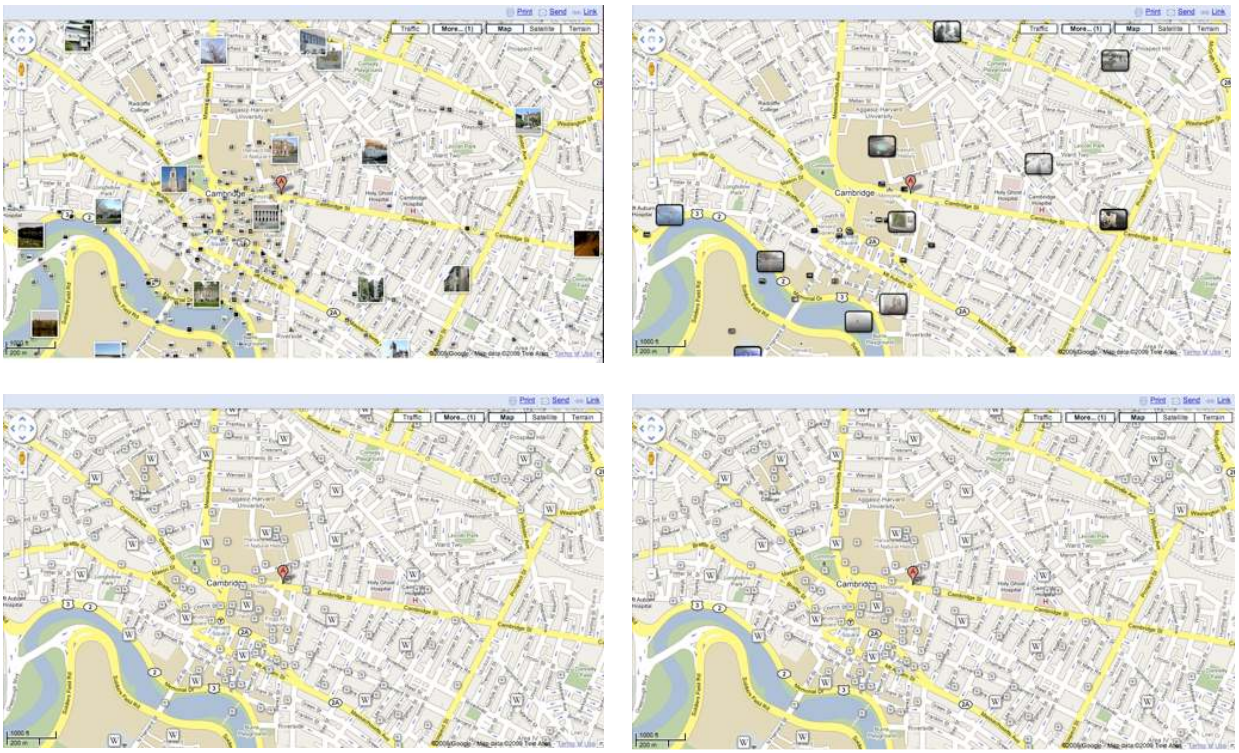
Google Map identifying the Harvard GSD at 48 Quincy St, Cambridge MA 02138.

Map Layers

Additional layers of information also can be added to a Google map. These layers are designed to further the understanding of a place. For example the photos, videos and Wikipedia data available for the area surrounding the GSD at 48 Quincy Street is all user-generated content. For this reason the content may not be metrically accurate but could be useful in understanding the user quality of a given site.





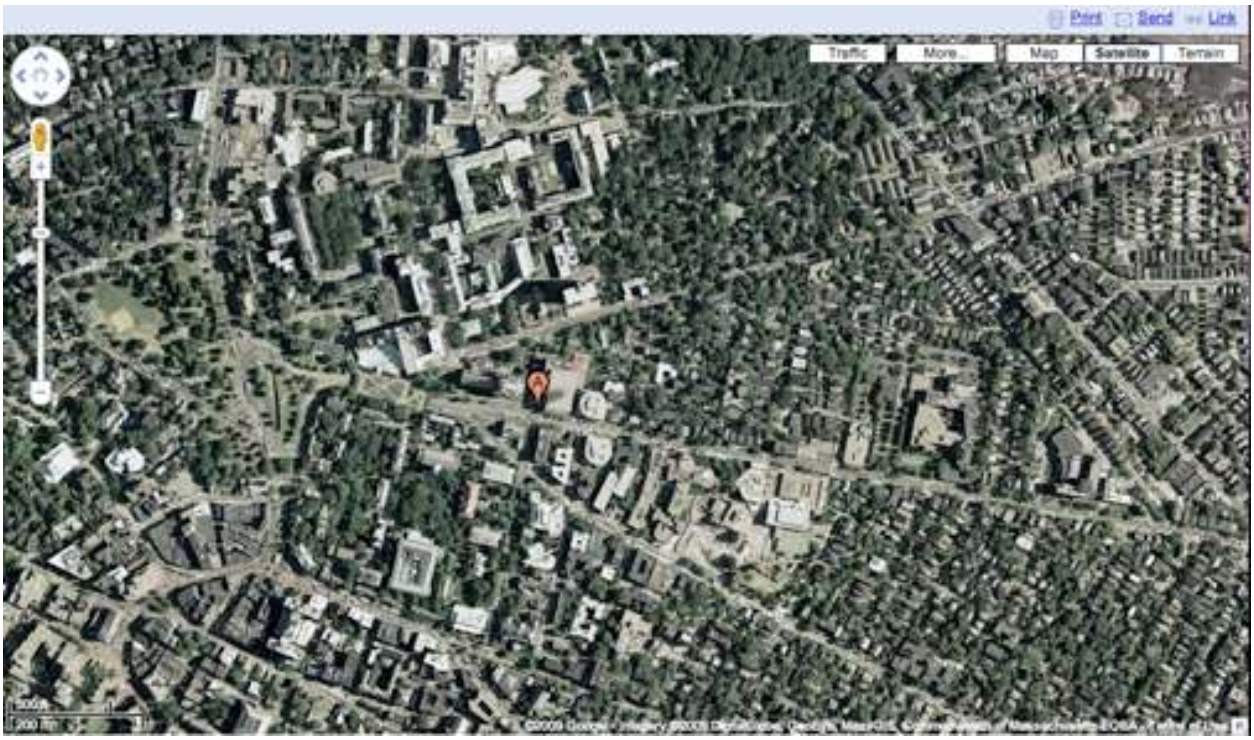


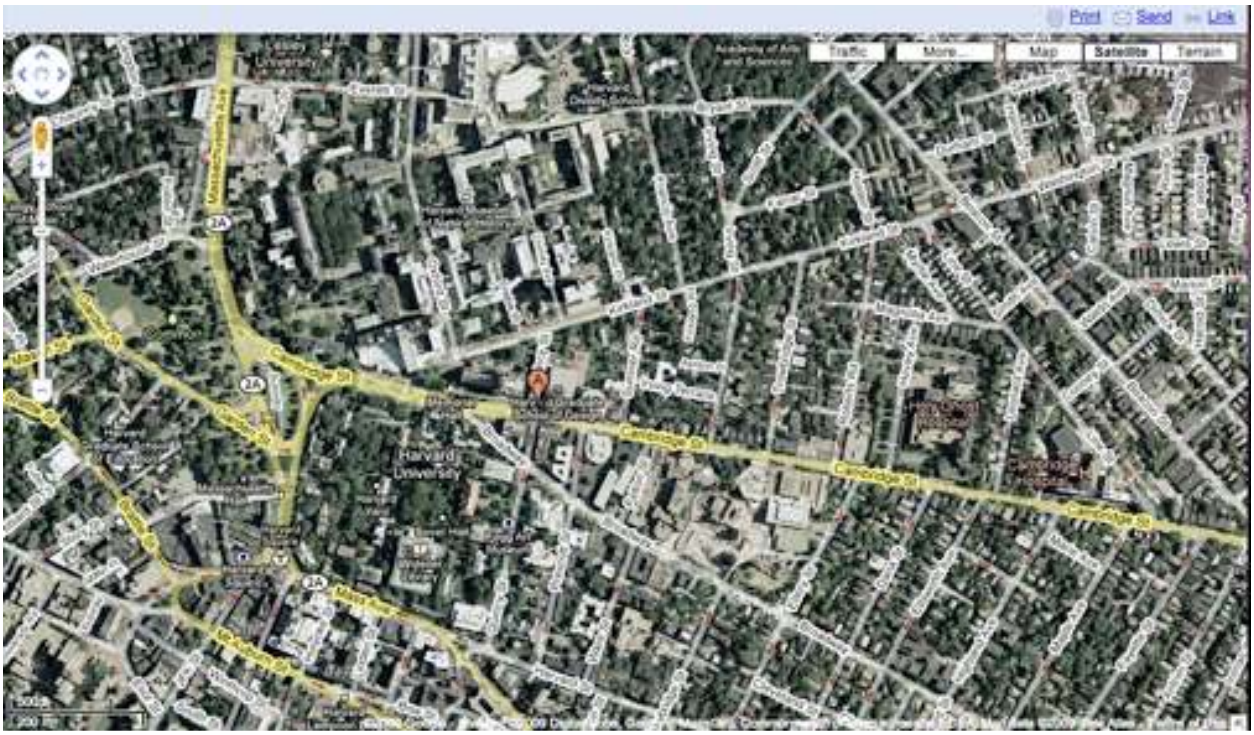
Clockwise from Top Left (All maps are Google Maps identifying the Harvard GSD at 48 Quincy St, Cambridge MA 02138).
Terrain, Live Traffic Conditions, Videos Available, Transit, Wikipedia Entries, Photos Available

Satellite Map

Satellite generated photographs of the majority of the inhabited planet. Since these maps are temporally sensitive and static they are sometimes they are not current (ie photos taken after a hurricane.) These are projected images, which are stitched together to create a 'flat' image, which creates an inconsistency of color and projection over a city. Also, time of day is not dynamic. Images show one time of day and sun, sky, foliage or water condition. Data is drawn from multiple sources to create these maps.

In design this view is often used at the urban planning scale to show how a new development could fit into an existing context, this type of mapping is a traditional design tool, although the satellite imaging is a relatively new technology. This is a useful mapping technology for the Zofnass program since it also identifies foliage and some relative building depth/height is shown due to shadows cast.



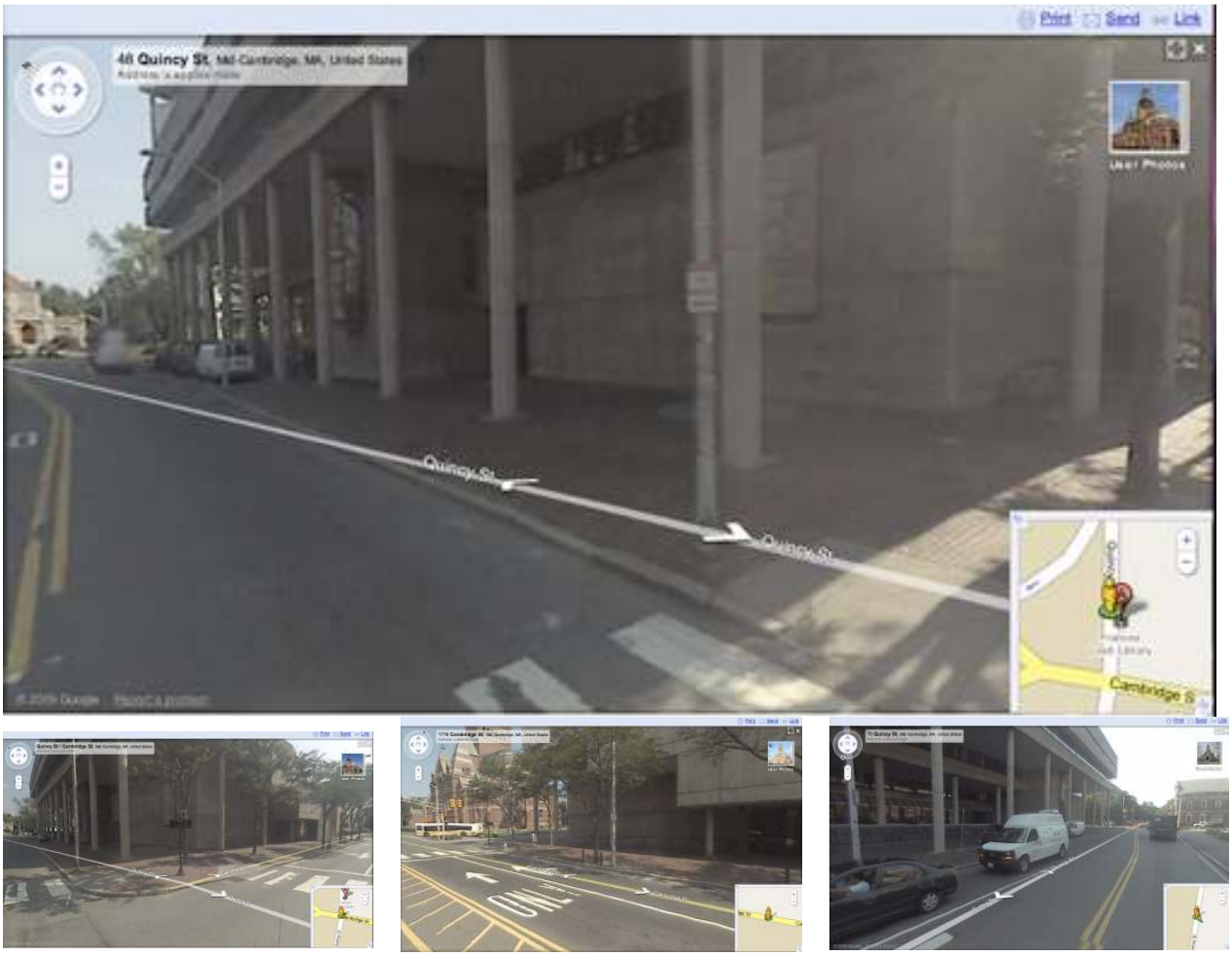


Top: Google Satellite Map identifying the Harvard GSD at 48 Quincy St, Cambridge MA 02138.
Bottom: Labeled Google Satellite Map identifying the Harvard GSD at 48 Quincy St, Cambridge MA 02138.

Street View

These are photos taken from a Google car of the ‘street view’ of any given street. Limited to access to an area and the time of day in which the photo was taken. Again these photos are stitched together to create a consistent projection, sometimes unsuccessfully.

In design this view is often used to integrate a rendered image of a future design to show how that design could integrate into an existing context from a user view, often used in marketing and advertising of architectural or urban design projects, one of the most readily 'understood' visualization tools as it mimics human visual experience from eye level.



Google Street View of the Harvard GSD at 48 Quincy St, Cambridge MA 02138.

User Generated Content

Users contribute their thoughts on a give place (ie restaurant reviews, best of lists) creating an organic, grass roots conception of a city which is free to interpretation and individual opinion. This type of documentation allows for ongoing and unedited content. Although the feedback is limited to those who choose to participate in a technology user group.

In design these maps can be used to identify 'hot' or 'up and coming areas' which may not have the visual trappings of wealth or development but which are greatly appreciated by users

Sim City

Sim City is a city-building simulation computer game developed by Maxis, a subsidiary of Electronic Arts. The game allows players to create a region of land by terraforming, and then to design and build a settlement which can grow into a city. Players can zone different areas of land as commercial, industrial, or residential development, as well as build and maintain public services, transport and utilities. For the

success of a city players must manage its finances, environment, and quality of life for its residents. Night and day cycles and other special effects are integrated into the game. External tools such as the Building Architect Tool (BAT) allow custom third party buildings and content to be added to the gameplay. The gamer can play in God Mode or Mayor Mode, where the actual city building is conducted. Players can build transportation networks, which include roads, streets, avenues, highways, railways, subway lines, and bus stations. Sim City was introduced into the discussion as part of the RTF workshop.

The game simulates urban decay and gentrification with buildings deteriorating accordingly. Buildings originally constructed for occupation by higher wealth tenants can now support lower wealth tenants in the event surrounding factors forces the current tenants to vacate the building; this allows certain buildings to remain in use despite lacking its initial occupants. Buildings and lots can now be constructed on slopes.

Funding can now be adjusted for individual buildings, allowing users to specify how much money should be spent to supply a service in accordance to the local population. Maintenance expenses for public utility facilities will increase as they age. The maximum output of facilities also decreases as they get older. The rate at which facilities age is dependent on the percentage of its capacity being used and the level of funding being given to it.

The temporal nature of Sim City make it a precedent worthy of examining. Algorithms are in place which mimic everything from the likelihood of a natural disaster to the ebbs and flows of local economy. Although Sim City is generally not perceived as an academically useful planning tool it does offer a precedent of layers many, many types of data from environmental to historic into a feedback loop that mimics the development of a physical city.

Google Street View of the Harvard GSD at 48 Quincy St, Cambridge MA 02138.

Second Life

Second Life (*SL*) is a virtual world developed by Linden Lab and is accessible via the Internet. A free client program called the Second Life Viewer enables its users, called Residents, to interact with each other through avatars. Residents can explore, meet other residents, socialize, participate in individual and group activities, and create and trade virtual property and services with one another, or travel throughout the world, which residents refer to as the grid. Second Life was examined by students during the RTF workshop.

Built into the software is a three dimensional modeling tool based around simple geometric shapes that allows a resident to build virtual objects. This can be used in combination with the Linden Scripting Language, which can be used to add functionality to objects. More complex three-dimensional Sculpted prims (colloquially known as sculpties), textures for clothing or other objects, and animations and gestures can be created using external software. The Second Life Terms of Service ensure that users retain copyright for any content they create, and the server and client provide simple digital rights management functions. Second life's content is user-generated and much of the actual built world has been replicated. Second life has an economy, money is exchanged, and goods and services rendered. Although Second Life does not serve the needs of the Zofnass Program it does offer the precedent of a simulated world of complexity. SL's development begins to approach the complexity of the physical world and is a promising step toward achieving the complexity of simulation needed to provide feedback at the urban scale. The multi-user content generated reflects more realistically the development of an actual urban environment.

Top: Second Life NASA station on Mars. Bottom Left: Second Life Amsterdam, The Netherlands. Bottom Right: Second Life Guggenheim Museum New York, New York.

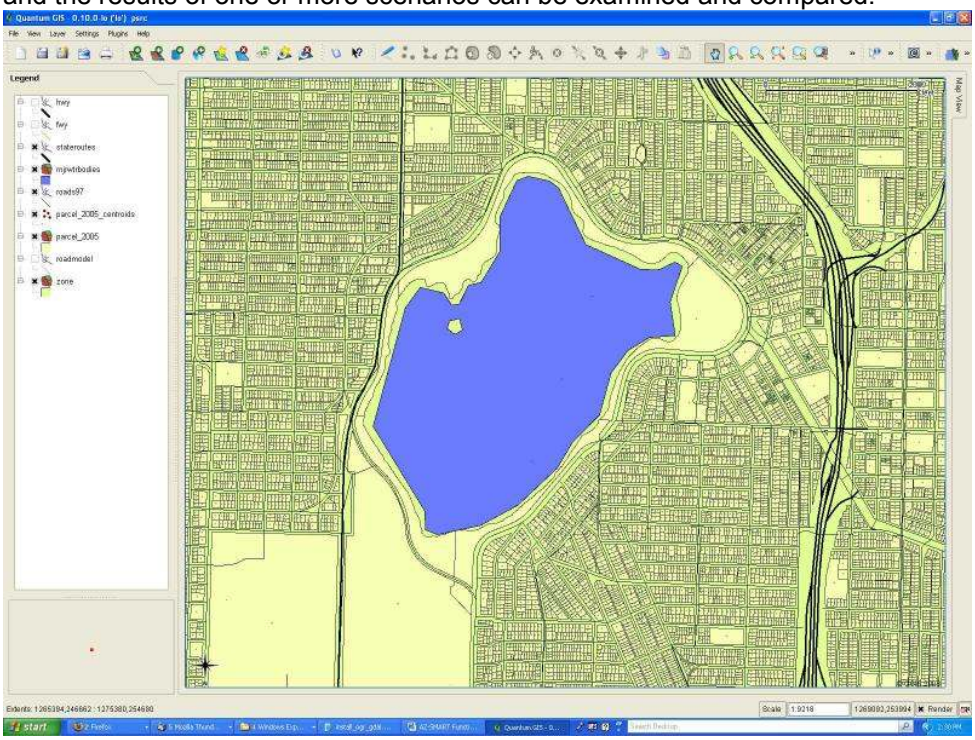
UrbanSim

UrbanSim is being developed by an interdisciplinary research group at the University of Washington in Seattle. It is within this planning context that the UrbanSim model has been developed. The model implements a perspective on urban development that represents a dynamic process resulting from the interaction of many actors making decisions within the urban markets for land, housing, non-residential space and transportation. For example: Households make choices about whether to move, and if they move, where to locate, businesses make similar decisions, Developers make choices of what properties to develop or redevelop and into what use, at what density and scale, governments make infrastructure investments, and place constraints on development in the form of land use plans, density constraints, environmentally-sensitive land restrictions, urban growth boundaries, and many other policies.

By treating urban development as the interaction between market behavior and governmental actions UrbanSim is designed to maximize reality, thereby increasing its utility for assessing the impacts of alternative governmental plans and policies related to land use and transportation. Thus, the model design enhances the strategic planning capabilities of MPOs and other state and local agencies needing to evaluate growth management policies such as urban growth boundaries, assess consistency of land use and transportation plans, and address conformity with respect to air quality implementation plans.

Running the model requires exogenous input information derived from: population and employment estimates, regional economic forecasts, transportation system plans, land use plans, land development policies such as density constraints, environmental constraints, and development impact fees

The user interacts with UrbanSim to create "scenarios," specifying alternative packages of forecasts, land use policy assumptions, and other exogenous inputs. The model is then executed for a given scenario, and the results of one or more scenarios can be examined and compared.[4]



[4] UrbanSim website http://cuspa.washington.edu/description/

Mapping and Simulation Hardware Strategies

This paper did not focus on the Hardware needed to express the majority of these technologies. The Value Lab (see photograph) was introduced during the RTF workshop as a potential platform for advanced urban simulation. The GSD does not currently have a dedicated equivalent to the ETH's Value Lab and the Zofnass Program therefore does not currently engage with a similar simulation platform. However, the possibilities for communicating complex graphics and 3D models in a collaborative environment are vastly increased by access to facilities similar to the Value Lab. Students were welcome to use the Value Lab during their time at the RTF workshop.
There are several ways to approach the use of hardware in the Zofnass Program. Although this was not the focus of this research the hardware platforms available and required.

- Integrate with existing technologies through the Computer Resources Group at the GSD to use available hardware to create a platform through which to convey urban simulations
- Partner with the GSD Technology group and/or MIT Media lab in the access of advanced hardware technologies to convey information (see Value Lab discussion)

Conclusions

The Zofnass Program could integrate into the team's work the findings of the ETH Reconstruct the Future! and the subsequent research documented in this paper. To create recommended guidelines for sustainable large-scale projects as is the intent of the Zofnass Program it is necessary that the Zofnass Program take a stance on the use of technology, specifically urban modeling and simulation technology in the practice of designing large-scale projects, be they infrastructure or urban design projects. This research indicates that the use of urban simulation software is both necessary and rapidly developing technology.

There are also several ways to approach the use of software in the Zofnass Program.

- Create a proprietary umbrella system or software that is integral to the Zofnass Program that allows existing software(s) from multiple disciplines (ie biology, geology, GIS) to layer and interact to simulate how a large scale infrastructural design move could influence a given system or how these systems could interact unexpectedly or in interesting unforeseen ways
- Partner with computer scientists and/or programmers at Harvard or MIT in the development of an open source Zofnass Program software which would be made available with the rating system and which would be integrated with the rating system
- Purchase an existing technology and work with the developers to tailor that software to best fit the needs of the Zofnass Program
- Use existing technologies to create schematic design and design development phase feedback loops at the urban simulation scale for the refinement of infrastructural design decisions
- Use existing technologies to model and advocate for decentralized local infrastructure versus larger scale infrastructure
- Partner with the ETH and/or other universities in the integration of existing Urban Simulation technologies as part of the Zofnass Program
- A process for developing a useful Urban Simulation technology could look like the process developed by Paul Waddell and his team at the University of Washington in Seattle. See chart below.

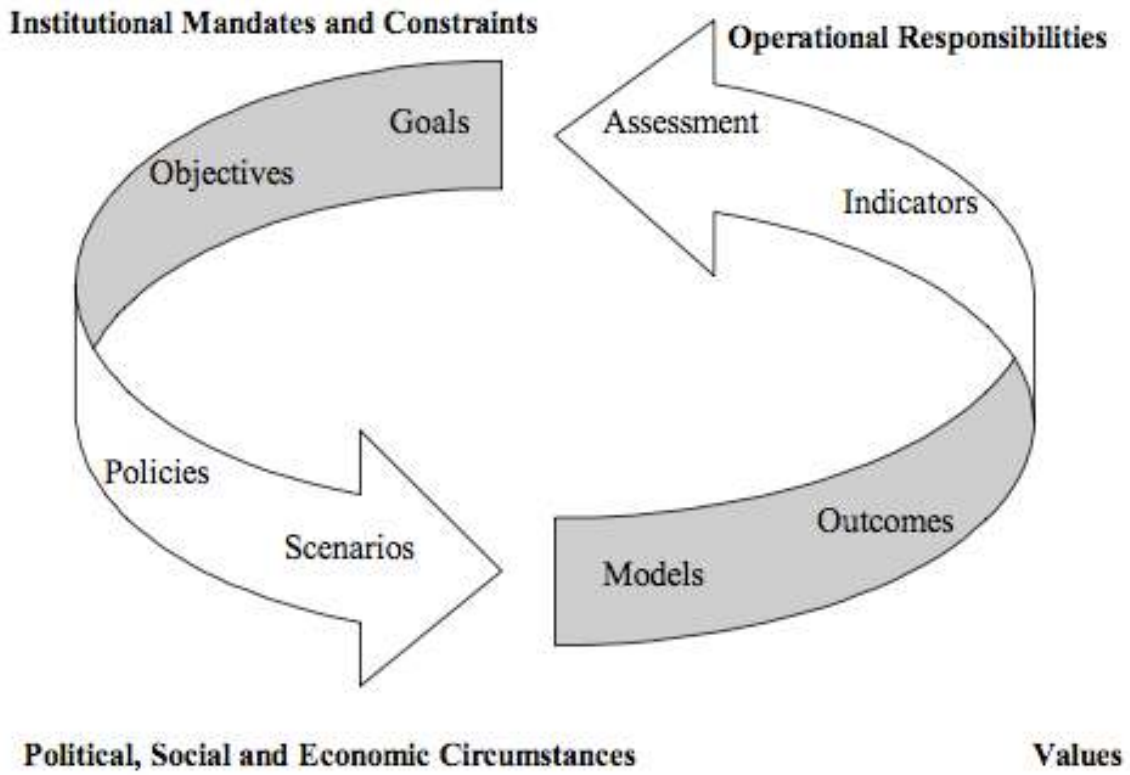


Figure 1: Models in the Policy Process

The model development process we propose is summarized in the following steps:

1. Assess the institutional, political and technical context
2. Assess stakeholders, value conflicts and public policy objectives
3. Develop measurable benchmarks for objectives
4. Inventory policies to be tested
5. Map policy inputs to outcomes
6. Assess model requirements
7. Prepare input data
8. Develop model specification
9. Estimate model parameters
10. Calibrate model system
11. Validate model system
12. Operational use

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Summary + Zofnass Recommendations

It is clear from the RTF Workshop and the current research of the Zofnass program that the field of urban simulation is a varied and nascent study and that the use of a mathematical based model to fully predict the ramifications of an infrastructural scale project is not yet an accurate approach. However, it is necessary that the Zofnass group embrace, document and incorporate progressive technology as the team's research continue.

The ETH Value Lab sets an important precedent of what the future for design and collaboration platforms, one that the Zofnass group should adopt. The space of the Value Lab projects a sense of a commitment to the future and commitment to the best, newest and most compelling approaches to large scale design. Additionally, it is a space of collaboration and visualization. Spaces of collaboration are necessary to bring together a diversity of fields, expertise and discipline. These are the groups of people necessary to produce a successful design of an infrastructural scale. It is well known that communication of a design process between designers, consultants, clients, researchers and the public is as important as the intent of the design. A platform such as the Value Lab would allow Harvard and the GSD to collaborate at a new level and would increase the ability of the Zofnass program to disseminate and enrich the products of its research.

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Resources

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http://www.urbansim.org/
http://blog.121pcs.com/urban-simulation.html
http://www.docstoc.com/search/urban-simulation/
http://www.vis-sim.org/services/overview_us.shtml
http://www.satimagingcorp.com/svc/3d-city-and-urban-modeling.html
http://www.google.com/intl/en/sketchup/3dwh/help_model_city.html
http://www.fugroearthdata.com/servicescat.php?cat=modeling
http://www-video.eecs.berkeley.edu/~avz/3d/3d.html