Journal of Theoretical and Applied Electronic Commerce Research
ISSN 0718–1876 Electronic Version
VOL 7 / ISSUE 3 / DECEMBER 2012 / 88-100

This paper is available online at
www.jtaer.com
DOI: 10.4067/S0718-18762012000300009

Virtual Cities in Urban Planning: The Uppsala Case Study

Cristina Videira Lopes[1] and Christer Lindström[2]

[1] University of California, Bren School of Information and Computer Sciences, Irvine, USA, lopes@ics.uci.edu
[2] Institute for Sustainable Transportation, Stockholm, Sweden, christer.lindstrom@podcar.org

Received 14 May 2012; received in revised form 15 August 2012; accepted 15 August 2012

Abstract

Gearing cities towards a path of sustainability is a daunting task. The urban models that we have come to accept during the 20th century need to be revisited, but change, even if welcomed in abstract, is usually met in reality with enormous resistance from the economic and political models that underlie our cities. Some of the most powerful tools for promoting change are those related to conceptualization and visualization. When considering urban plans that aren't just incremental improvements over what already exists, city officials, urban planners and the general public must be able to visualize not just the merits of those plans in isolation, but how they interact with all the infrastructure that already exists. This paper describes one such urban plan that has been under consideration in the city of Uppsala, Sweden, for the past 5 years: a solar-powered Personal Rapid Transit (PRT) system connecting the main train station to the Hospital and the University. The process of discussing the PRT system included the development of a virtual reality simulation of parts of the city. We report on the process and role of this virtual reality simulation.

Keywords: Virtual cities, Virtual reality, Personal rapid transit, Urban planning, Traffic simulation

1 Introduction

Urban planners, real-estate developers, and the general public are aware that the current carbon based energy life is not sustainable, and that innovative approaches to urban development are needed. However, the transition into new forms of planning is quite difficult. The experience, knowledge, and execution of planning for urban developments are upheld by a fragmented base of stakeholders, many times having inconsistencies between their databases. There is no common picture of what pieces of infrastructure the cities contain, and how they operate and integrate with each other. Stakeholders' sharing data and engaging in dialog over longitudinal projects is one of the main obstacles on the path towards smart cities.

Most software tools for making 3D models, simulations, and presentations are developed and marketed assuming the above context. This means that the tools themselves are perpetuating the current fragmented structure of urban planning, becoming a limiting factor in the goal of having a holistic, contextual view of any given urban sector. The market of IT for urban planning is dominated by tools that have been focusing on specific areas of technical expertise rather than trying to support the coordination and integration aspects of these projects.

To a large extent, the popularity of Google Earth shows the need for a common information infrastructure that goes beyond what the professional desktop-based tools provide. However, as popular as Google Earth has become, the control and interaction models underlying Google Earth are lacking some important features for supporting an effective, actionable common operating picture for real urban plans. There is a void in tools and systems that target coordination and integration, that focus on context as much as content. Bettering urban planning tools by making them more holistic and collaborative, and by engaging stakeholders in the decision processes, may have an immediate impact on bettering the urban plans themselves in terms of how cities use the available resources. This general belief is shared among many researchers in urban planning (e.g. [19], [29], [32]).

3D visualization tools have long been used in architecture, real estate development and urban planning. Typically these tools have three kinds of usages: (1) marketing and community education; (2) geographic information analysis; and (3) design and engineering of buildings and structures. Marketing and community education tools consist of 3D computer animation movies usually designed to evangelize the community about the project, i.e. to sell the vision or idea; geographic information analysis tools consist of Geographic Information Systems (GIS) such as the ESRI toolset, and they are used to study the technical feasibility of the different aspects of the projects; finally, design and engineering tools include professional CAD tools such as AutoDesk that are used long after the main urban planning decisions have been made. There seems to be a gap between tools for evangelization (1) and tools for technical design (2 and 3). Yet, if cities are to engage in sustainable development, it is critical to provide tool support for frank discussion of urban planning ideas.

We posit that such gap will be filled by tools that virtualize cities, as many aspects as possible, in intuitive and accessible manners. This idea is not new. Virtual reality has been reportedly used for GIS and urban planning since the 90s (see Section 2), but somehow it hasn’t quite entered the practice of urban planning, especially in early phases. Intrigued by this gap, we set to conduct a study on the use of immersive virtual reality for early stage urban planning. What are the hurdles? Who builds the models and who uses them? How do stakeholders interact with, and through, the model? Does virtual reality enable new kinds of processes and new levels of engagement, or are the VR tools just better visuals for the exact same old processes? And, most importantly, do virtual cities ultimately lead to better, more sustainable real-world city planning or are they a distraction?

This paper describes the virtualization of the city of Uppsala, Sweden, in the context of a novel urban transportation system that is being considered. Specifically, city officials and several city stakeholders are considering the deployment of a Personal Rapid Transit (PRT) system connecting the main train station to the Hospital and the University. PRT, also known, as *pod cars*, are automated vehicles that carry a small number of passengers (up to 6) traveling together to the same destination [16]. The pod cars run on dedicated guideways, or tracks, built above the ground. Depending on the model, they can be suspended on or supported by the guideways. The most high-profile pod car system in use today is the one in the Heathrow airport, London, deployed in 2011 (see Figure 1). Another high-profile case is the PRT system currently being implemented in Masdar City [28], [30], a city designed from scratch to be energy efficient. At the core a possible PRT system in Uppsala is the belief that it would reduce air pollution, energy consumption and operating costs, while moving more people faster than cars and buses do. Over the years, proponents of PRT systems have produced several technical studies and simulations that seem to support those claims (e.g. [12], [21], [26], [27], [39]).

Figure 1: Pod cars in the Heathrow airport. © Advanced Transport Systems Ltd. www.atsltd.co.uk

PRT systems, however, are far from being incremental changes over our existing cities' infrastructures; on the contrary, they require a substantial reconceptualization of our cities, and, partly due to that, they have generated considerable controversy over the years. Several concerns have been voiced of technical, operational, regulatory and aesthetical nature. For example, some doubt the cost-effectiveness of this mode of transportation in densely populated cites [38]. Others doubt whether small vehicles provide enough capacity to serve the large crowds that are offloaded in mass transit stations. With respect to urban design, the tracks are elevated, not at ground level; this results in uncertainties about how such systems will look and feel as people walk under them and see them through their windows. In [8], Cottrell gives a good overview of the issues surrounding PRT systems and of the research that has been published about them over the years.

In spite of these concerns, there seems to be a growing interest in PRT systems because of their potential to reduce operating costs and pollution. The highly visible deployment in Heathrow may be a turning point in the public acceptance of this form of transportation. Feasibility studies have been done for a few cities in Sweden, including Uppsala [35]. Nevertheless, when officials of traditional cities and local stakeholders consider something as radical as a pod car system in their own cities, such as the case of Uppsala, technical doubts, aesthetic insecurities and a general fear of radical change are unavoidable. In [34], Tégner et al. summarize the obstacles for the uptake of PRT in Sweden.

In order to address these issues, Uppsala city officials commissioned a small 3D virtual reality study of the area around the main train station. The study was later expanded to a 3x1.5 km^2 area. These officials wanted something beyond a generic 3D computer animation movie about pod car systems -- those had been done before. They wanted a virtual environment that depicted an accurate and realistic rendition of Uppsala, and that could serve as an *editor* for laying down the possible deployments of the track and stations, as they weren't sure what the best placements would be in the holistic context of the existing urban elements. Furthermore, they wanted a dynamic environment consisting of moving traffic and pedestrians, one that could be observed from many points of view, and that could be easily changed. In short, they wanted to have an integrated virtual rendition of as many aspects of the city as possible, so to assess the pod car system in the context of all those aspects.

This paper describes the technology that was employed for meeting these requirements, and the main observations and lessons learned from this project so far, in particular the role that the virtual reality model of Uppsala played in stakeholder discussions and in the evolution of this urban planning process. Videos from this project can be found on Youtube (Site 1). At the time of writing this paper, the decision of whether to apply for funding for the PRT system is still under deliberation in Uppsala.

2 Related Work

Several studies exist on the use of Information and Communication Technologies (ICTs) in urban planning and smart cities, such as broadband deployment, e-services and open data (e.g. [1], [2], [6], [14], [20], [22], [23]). Those are related to this work in trying to unveil the actual experiences and observations from the deployment of technology. Our work focuses on one particular kind of technology: virtual reality.

The idea of using virtual reality for GIS and urban planning is quite old; a substantial amount of work can be found in the literature since the 1990s, when advancements in computer graphics made that idea possible (e.g. [5], [9], [15], [18], [33]). As early as 1999, researchers envisioned participatory GIS systems based on virtual reality (e.g [17], [31]). Adoption of those ideas in practice, however, has been quite slow.

The popularity of the virtual world Second Life during the period 2007--2009 has generated a renewed interest in virtual reality for GIS. Because its build tools are so easy to use, several experiments in urban development and architecture have been made there. Our work in virtualization of urban plans started in Second Life [24], but it soon moved to OpenSimulator [25]. ArchVirtual (Site 8) is an example of Second Life architectural experiments that

This paper is available online at
www.jtaer.com
DOI: 10.4067/S0718-18762012000300009

evolved into a commercial endeavor. ArchVirtual is now using OpenSimulator, so it shares many similarities with the infrastructure presented here. Similar efforts connecting OpenSimulator to GIS are being made by several people around the world (e.g. Site 9, Site 10). To our knowledge, our virtual Uppsala model is the largest and most feature-rich urban planning model ever made with OpenSimulator/Second Life.

Also recently, but outside the OpenSimulator/Second Life technologies, UrbanSim (Site 11), particularly its UrbanVision application [37], is the closest work to virtual Uppsala. UrbanVision currently supports a virtual rendition of the San Francisco Bay Area, and is being used by urban planners in that area. It shares many similarities with our system, namely capabilities for 3D modeling and for simulating traffic and pedestrians. UrbanVision is a relatively recent addition to UrbanSim, and is not available for distribution, so we cannot make any meaningful comparisons.

But in spite of the very large body of work in virtual reality technologies for GIS, very few papers exist reporting on actual experiences of use of those technologies in action for the purposes of urban planning. Some papers report on the difficulties of modeling the cities at large-scale, and consequent techniques used for doing so [10]. In our case, even though the area was relatively large, the modeling work was relatively straightforward: we used the well-known paradigm of focus-plus-context [3] in order to speed up the modeling work for the purposes of the plan at hand.

Thompson et al. [36] is, perhaps, the publication that is closest to reporting actual experiences. That paper reports on an ongoing relationship between Northumbria University and the local authorities *in order to achieve one single authoritative city model that can be used for a variety of applications.* The model is hosted by the university, and the urban planners access it remotely. It is stated that the model is offering many benefits to the local authorities, resulting in time and cost savings, but no further information is provided. The paper reports on the emerging issues surrounding the discovery, reutilization and conversion of existing data, as well as on other non-technical, but equally important, issues of origin and ownership of data. As stated in Section 5.3, we faced similar issues with data acquisition. The paper also mentions the existence of a dedicated point of contact between the University and the urban planners, similar to the process we put in place. In their case, that person is also the modeler. In our case, that person did some modeling at points, but was in no way the main modeler; we found no need to add direct communication between the main modelers in the United States and the urban planners in Uppsala.

The main focus of this paper is the case study of the social process surrounding virtual Uppsala and its role in the planning process of the PRT system, and not the virtual reality infrastructure itself. Because the use of virtual reality cities in urban planning is just emerging, we believe our experiences with the city of Uppsala are valuable pieces of information for others to be able to avoid mistakes and reproduce successful strategies for the benefit of sustainable urban plans.

3 Methodology

In spite of the substantial body of work related to virtual reality in activities related to urban planning (see previous Section), we could not find any reports of *experiences of use in actual real-world projects*. This paper presents one case study of the use of a virtual city in urban planning -- the PRT project in the city of Uppsala, Sweden -- spanning over a period of 4 years. Merriam-Webster's dictionary defines a case study as follows:

Case Study. An intensive analysis of an individual unit (as a person or community) stressing developmental factors in relation to environment.

This definition does not establish any specific methodology; it simply implies the scope of what's to be studied. In our particular case, the scope is the virtual Uppsala model that we built (see Section 4) and the group of stakeholders responsible for brainstorming and supporting (or not) such a radical transportation plan. The focus of this study is neither the technology nor the virtual city itself, but the role that they played in the real-world brainstorming and decision-making process. As such, we are interested in *qualitative* observations and in formulating grounded hypotheses about the value and role of virtual cities within urban planning.

Our approach to this study was fairly opportunistic, close to the grounded theory methodology [13] – although we did not follow the formalities of that methodology. By opportunistic we mean that there was no upfront experiment design and no upfront hypotheses; instead, we took advantage of the opportunity offered in the context of a real business contract in order to take notes and make observations along the way that would allow us to identify the value of virtual cities for the ultimate goal of fostering more sustainable urban plans, and to formulate hypotheses.

The influential Penguin Dictionary of Sociology [1] has, for years, cautioned that *[...] a case study cannot provide reliable information about the broader class, but it may be useful in the preliminary stages of an investigation since it provides hypotheses, which may be tested systematically with a larger number of cases.* This subordinate view of case studies has been questioned most notably by Flyvbjerg [11], who clarifies several misunderstandings surrounding the status of case studies within social science methods. In spite of taking Flyvbjerg's position on the scientific value of case studies, we agree with the cautionary note that our qualitative observations should not be generalized, and that many more case studies of this kind need to be conducted before concluding that virtual cities help (or hamper) real-world urban planning.

Journal of Theoretical and Applied Electronic Commerce Research
ISSN 0718–1876 Electronic Version
VOL 7 / ISSUE 3 / DECEMBER 2012 / 88-100

This paper is available online at
www.jtaer.com
DOI: 10.4067/S0718-18762012000300009

We first describe the major events and milestones of the virtualization project, and then explain the data for the observations made later on in the paper.

The virtual reality rendition of the possible pod car system in Uppsala was originally commissioned by the City of Uppsala in 2009. The first deliverable consisted of an area of 750x750 m^2 around the main train station, and the goal was to conceptualize/visualize a possible pod car station in that area. Specifically they wanted to visualize how large groups of people arriving in trains could be served by pod cars. This work complemented several other feasibility studies, all of them quantitative in nature -- cost/benefit analyses, traffic and people flow, etc. While these theoretical studies showed that the concept was viable, city officials had some concerns about its operation in practice. That first deliverable was finished towards the end of 2009. Several political and strategic deliberations ensued in Uppsala regarding the pursuit of the pod car system plan. In 2011, a second piece of work was commissioned, this time targeting an area of 3x1.5 km^2, a considerable portion of the entire city. The goal of this second phase was to conceptualize/visualize how the pod car system would connect the main station to important destination areas such as the Hospital and the University. This second phase was commissioned by the City of Uppsala, the County Academic Hospital and the University Real Estate Company (Akademiska Hus). The second deliverable was finished in April of 2012.

The virtualization and several byproducts of it (videos, pictures) have been frequently shown to the stakeholders -- city officials, urban planners, politicians, and real estate developers -- throughout the duration of the project, both in individual and in group meetings, as well as in formal and informal gatherings. The data for this case study consists of the feedback and observations collected during those meetings and gatherings. Additional methodological details are presented in Section 5.

4 Virtualization Infrastructure

The virtualization infrastructure is based on free, open source software. The server side uses OpenSimulator (Site 2), a platform for developing Second Life-like virtual environments. The client side uses one of the multiple Second Life viewers (Site 3). We describe how we have used these open source components.

4.1 The Server Side

The area is divided into a 2D grid of 256-meter regions. There are 6 x 12 = 72 regions total. In turn, the regions are grouped in *sectors* of 3x3 regions, each sector running in a separate simulator. In total, there are 8 simulators for this area (see Figure 2).

Figure 2: Simulated area divided in a grid. White lines denote region divisions (256x256 m^2); red lines denote simulator divisions.

We use OpenSimulator in a standard grid configuration, with one central *Robust* server, and with the simulators all sharing the grid resources. During different phases of this project, we placed the simulators in a variety of servers, from our own machines to AWS EC2 (Site 4). We have developed a simple systems administration layer on top of OpenSimulator that allows us to very quickly deploy simulators in whatever servers we need them to be on.

4.2 The Viewers

We use primarily 2 viewers, both open source: Imprudence (Site 5) and the Zen viewer (Site 6). Imprudence allows us to create very large structures as well as importing/exporting objects. Zen is based on the Linden Lab V3 code base, meaning that it supports all the latest graphics features such shadows. It also comes with presets for creating visually stunning environments regarding the sky, the water and the light, allowing us to simulate day/night scenes, different kinds of weather, etc.

4.3 Terrain

With an external toolset, we are able to generate terrains from GIS data, embedded with aerial images. These realistic aerial-image terrains, by themselves, provide a fair amount of immersion, even before any building is modeled. They also give us the footprint for placing the buildings in the scene and for visualizing the roads and vegetation (see Figure 3).

Figure 3: Terrain detail. Mesh consisting of elevation data and aerial image

4.4 The Build Process

To a large extent, the build process is the same as any build in Second Life / OpenSimulator. We have been using primarily prim buildings, but we also have sculpties and meshes. We have taken a fair amount of pictures of the building façades in Uppsala, and used them to texture the buildings (see Figure 4).

The build process was a collaborative and iterative effort involving a total of 9 people over the 4 years of the project. Modeling work was done only in certain periods of time, not during the entire 4 years. Most of the team that modeled the buildings was in the United States, and did not visit Uppsala. One person (one of the co-authors) was in Sweden and made frequent visits to Uppsala and to the United States. The model of the PRT system was done by an engineer in Sweden using an external program, and following an existing layout plan. That model was then imported into the virtual reality environment semi-automatically. At critical parts of the project, the entire team met inside the virtual reality environment (it supports voice chat) in order to coordinate the work and keep everyone updated about the outcomes of stakeholder meetings. But besides coordinating the work at a high level, very little coordination was necessary in order to assemble the complete virtual reality model. Specifically, there was not much need to exchange pieces of the model over email or shared storage systems, because the virtual reality infrastructure *is* the data storage and sharing infrastructure too.

Figure 4: Examples of buildings in the virtual Uppsala city.

4.5 Traffic Simulation

We developed a traffic simulation addon that is capable of driving thousands of vehicles all over the virtual area without this negatively impacting the performance of the virtual city. The traffic simulation runs on a separate server. The vehicles go from one end to the other without regards for *region* or simulator borders. The current traffic simulation/visualization has been developed from scratch, but the intention is to connect this technology to external traffic simulators (e.g. SUMO [4], [7]).

Currently, the hardest part of this simulation is the establishment of routes. The only way to infer the routes is by visual inspection and by insider's knowledge of the traffic flow and signs in Uppsala. Figure 5 (left) shows the waypoints for cars and buses around the station area manually placed on the ground. With areas like this one, 3km wide, setting up the paths that the vehicles use, and the speed limits, is a daunting task. In the future we hope to be able to get this information in some automated manner.

On the positive side, the podcar system, given that it doesn't yet exist, has been much more amenable to automation. We have automatically generated both the tracks and the routes from an existing plan (see Figure 5, right).

Figure 5: Left: Waypoints for cars and buses. Right: section of the pod car track.

Journal of Theoretical and Applied Electronic Commerce Research
ISSN 0718–1876 Electronic Version
VOL 7 / ISSUE 3 / DECEMBER 2012 / 88-100

This paper is available online at
www.jtaer.com
DOI: 10.4067/S0718-18762012000300009

4.6 Pedestrians

Since 0.7.3, OpenSimulator supports server-side bots that are scriptable in-world. We have used that facility to create over 100 standing/sitting bots and a dozen of walking ones. The standing/sitting bots are very lightweight; the servers can handle hundreds of them. The walking bots, on the other hand, are relatively heavy, as they are part of the physics scene. The walking bots will be subject of substantial improvements in future virtualizations.

Figure 6: *Bots* enacting pedestrians.

5 Observations and Discussion

The methodological framework described in Section 3 guided our research work. As stated, we did not go into this study with pre-conceived ideas or hypotheses; instead, the main goal was to make observations about the stakeholders' reactions. Based on those observations we can then formulate hypotheses related to the value of virtual cities in urban planning.

In this section we describe the stakeholders' reactions to the virtual city over time, some of the observations we made, and lessons learned during this project. The section ends with a discussion that places these observations in the context of the research goals described in Section 1.

5.1 Reactions over Time

The first (smaller) model was presented to transit and railway authorities in Uppsala at the end of 2009. In the past, these authorities had expressed several concerns regarding the timely distribution of people arriving in trains into the pod cars. The results of mathematical simulations had not been sufficient to ease those concerns. The virtual reality model seems to have eased those objections: from being a serious operational issue, the evacuation of riders out of the main station became a non-issue from then on.

Having surpassed those operational objections, city officials and local stakeholders continued their deliberations on whether to pursue the PRT system or not. The next set of concerns had to do with laying out the pod car guideways throughout the historical part of the city, so as to connect the main train station to the main destination areas, namely the Hospital and the University. As such, in this second phase, the city was interested in visualizing the entire system, not just the travel center. Additional stakeholders joined the project, namely the County Academic Hospital, the University Real Estate company and the state-ran Vaskronan Real Estate company. The second, much larger, virtual city model was commissioned in 2011.

For this second phase, a first meeting was held with the entire group of stakeholders in October 2011, followed by several one-on-one meetings with individual stakeholders between then and March 2012. A final meeting with all the stakeholders was held in April 2012.

The goal of the first meeting of the second phase of the project was to explain the virtualization technology for those not familiar with it. Given that the technology allows many people to login and experience the model simultaneously in their own computers, we attempted to do that during that meeting. This was very problematic, as different people had completely different levels of literacy regarding 3D environments. Having no experience with online gaming or CAD tools, several people in that meeting were confused and, therefore, frustrated with the experience. In subsequent meetings, we decided not to do that, and instead drove the meetings with a shared projection of the virtual city on a screen. This worked much better, as it removed all the accidental complexities of people having to use a completely new tool without any prior training.

For the next three months, the series of one-on-one meetings focused on the particular needs of the stakeholders. Notes of those meetings were then sent to the modeling team in the United States. Those meetings were extremely productive, much more so than the large group meeting, because people had the opportunity to get acquainted with the capabilities of technology without social pressure to do so. Nevertheless, they were not directly manipulating the model; we were, and a projection was shown on a screen. As they became familiar with what the tool could do, they started engaging with the virtual model, making numerous requests regarding the placement of urban elements. Several online changes to the virtual city were performed during those meetings at the request of the stakeholders. For example, after seeing the Hospital area, the Hospital officials decided to make a change in the planning of one of their extensions (unrelated to the PRT system). The stakeholders were the primary agents for deciding the placement of the PRT stations, and those decisions were made during those meetings. Often, stakeholders would make requests of the form *Put the sun [at a certain time]* or *Put the camera [at a certain angle]* or *Put the station [there].* This dynamic interaction during the meetings was absolutely critical for the stakeholders' engagement with the PRT system.

The final meeting in April of 2012 brought all the stakeholders together again. This time they were all familiar with the virtual city, since they helped design certain elements of it. At this final meeting, the conversation changed from discussing the technical and operational issues of PRT towards discussing urban design related to that PRT system. For example, many people didn't like the track being all white, and wanted to change the color. The virtual city is now starting to serve as a common operating picture for urban design.

More importantly, in that final meeting there was among these stakeholders a strong support for pursuing the PRT system in Uppsala. A decision was made to seek political support from county-level officials. Such efforts are now ongoing.

5.2 Virtualization vs. Marketing/Educational Videos

When planning large urban projects, real estate developers often make use of a variety of new media for explaining those projects to the stakeholders. One of those media is video, mixing real images with computer animations depicting how the end result looks like. Countless examples of such videos can be found on the Internet. Using state-of-the-art commercial tools such as Autodesk/Maya, Blender, and other advanced 3D tools, it is possible to create videos that look so realistic that it is sometimes hard to distinguish reality from things that don't yet exist. Even though the media itself is agnostic to the uses that people make of it, these videos tend to be primarily marketing material, i.e. they are meant to evangelize or educate the viewer on a specific vision for the future.

During this project, additionally to the virtual reality environment described here, but separate from it, a conceptualization video was produced using Maya (Site 7). This computer animation movie depicts a rendition of the city of Uppsala and how a pod car system would look like in it. The movie has a marketing/educational tone to it. Pictures from this video are presented in Figure 7. This artifact allowed us to get anecdotal data pertaining to the stakeholders' reactions to the different media.

Figure 7: Pictures from a computer animation movie produced using Maya during the course of this project.

During the meetings of March/April 2012, we have shown the Maya movie to a few selected stakeholders. The computer animation movie was appreciated by those who were less knowledgeable about PRT systems and about the project, but that it was deemed irrelevant by those involved in the planning meetings, since nothing could be done with it -- no edits, no different viewing angles, etc. Anecdotal evidence from our interactions with these stakeholders over this video and over the virtual reality model suggests that these educational videos may be counter-productive for those who want to analyze the urban planning ideas with objective and pragmatic perspectives, and who want to be actively involved in the design decisions.

5.3 Social-Technical Context

Cities are complex socio-technical systems. Their planning and evolution, therefore, are also complex and sometimes chaotic processes. Often, scientific and technical arguments are not enough to make decisions. The decisions surrounding the use of public and private resources in urban areas are dominated by key players who have vested interests in particular outcomes, and, because arguments can always be counter-argued, politics always dominates those decisions. In this social context, it is difficult to gear cities towards more sustainable practices, especially those that require non-incremental changes. Even so, it is possible to break through established territories of influence by engaging with those officials who truly believe in their role as public servants and who want to leave a legacy for the common good. That was the case in Uppsala.

Besides the public officials, there also exists a large community of urban planning consultants who, again, have vested economic interests in particular practices of work. One of the things we experienced was how difficult it was to obtain GIS, land use and buildings data, even though we knew that data existed under some of these consultants' supervision. The problems surrounding the availability of data are well known, and several initiatives are being made all over the world towards *open data*, but there is still a long way to go to bring those ideas to practice in the context of urban data.

Another, somewhat surprising, observation from the process is that there is no need for the virtual city modelers to interact directly, or even meet, the stakeholders -- as long as there is a person in the middle who is capable of conveying (a) the tool limitations to the stakeholders and (b) the modeling requirements to the modelers.

In reflecting upon the process followed in this project, it is clear that the virtual model of Uppsala would have been of very little value had there not been a human agent meeting with the stakeholders regularly, getting them engaged with the model on a personal basis without requiring them to learn the virtual reality tool by themselves. The virtual city served as a concrete, tangible, common operating object to start and sustain the conversations across stakeholders; the engagement that the stakeholders developed towards the model made the process of understanding the plan much shorter. But it was the human agency over the model that made that engagement possible. The outcome would likely have been very different had we simply ask them to login to the model and make their own changes, even after training them. This may be a consequence of the lack of knowledge about the tool, and such a person may not be needed once the next generation of video-game-exposed urban planners takes over. In any case, the importance of the lack of proficiency with particular tools, and the effort it takes to train people to use them, should not be underestimated.

5.4 Discussion

Section 1 outlined some of the research questions we were interested in investigating in this case study. We discuss what we found in the context of those questions.

Q1. *What are the hurdles?* In our case, we found one of the major hurdles to be the lack of familiarity that urban planners had with 3D immersive environments. That lack of knowledge on how to interact with the tool was a blocking factor that required us to change our approach with the City of Uppsala. Instead of making the tool directly available to the stakeholders, as originally intended, we had to proceed with a tool expert as intermediary. In general these environments are much more complex than the IT tools that most people use, so we expect this hurdle to be a serious issue in the adoption of these environments, at least until these tools are sufficiently simplified or until a new generation of urban planners growing up in the age of video games is in charge. Another, less surprising hurdle was the difficulty in getting the necessary GIS data; this hurdle has been reported many times in other projects, so it seems to be pervasive.

Q2. *Who builds the models and who uses them*? In our case, we ended up building the entire model, although originally that was not our plan. This reiterates the importance of the hurdle identified above. In any case, the centralization of modeling was not an issue, as all stakeholders seemed to accept the model as an accurate rendition of the city. That agreement seemed to be more important than the feeling of ownership.

Q3. *How do stakeholders interact with, and through, the model*? The model seemed to be a good tool for brainstorming ideas. The engagement and enthusiasm during the one-on-one meetings was very high, because the model could be changed online to reflect the stakeholders' suggestions during those meetings. We were particularly surprised when some stakeholders (i.e. Hospital officials) started paying attention to parts of the model that were unrelated to the PRT system in question. We were also surprised when, in the later phase of the project, some stakeholders started using the model for urban design, additionally to planning. Our conclusion on this question is that the potential for serendipity in these virtual cities seems to be quite high.

Q4. *Does virtual reality enable new kinds of processes and new levels of engagement, or are the VR tools just better visuals for the exact same old processes*? Our observations regarding this question were mixed. On the one hand, the serendipity noted above seems to be a novelty brought to the table by virtual reality. On the other hand, the dominance of the political context in urban planning processes is undeniable, making the value of any single tool quite hard to assess.

Q5. *Do virtual cities ultimately lead to better, more sustainable real-world city planning or are they a distraction*? In our case, the virtual city was certainly not a distraction. The first piece of evidence for this was the fact that the city requested a second, much larger model after the first small model had been delivered. It was clear that the conversation about the PRT system was using the virtual city as its main driver, and that it had a strong influence in the continuing interest from the stakeholders. If the city of Uppsala decides to apply for funding for this ambitious project, that will be strong evidence that virtual cities are of great value for sustainable real-world city planning.

6 Conclusions

The road to sustainable cities is full of resistance to change. But without change, sometimes radical change, sustainability, especially in what relates to energy, won't come fast enough. One of the major obstacles to better energy solutions is the lack of tools for envisioning what the future might look like -- not in abstract but in the holistic context of each specific urban area: all aspects, all data, interconnected for that particular city. In considering alternatives, it is absolutely critical that the local stakeholders can visualize and, better yet, *feel* the consequences that those alternatives might bring to their everyday life. Technical expert assessments presented in abstract, even when they point to cost savings and better solutions, do very little to address the anxieties of those in decision positions and of the general public. We posit that virtual reality renditions of real cities, overlaid with the elements of sustainable urban plans, may play a major role in achieving sustainability in existing cities. This is a conjecture at this point, and one that needs a fair amount of research and case studies.

We have presented a case study of the use of a virtual city in the planning of real-world city, Uppsala, Sweden. City officials in Uppsala have been considering the implementation of a solar-powered Personal Rapid Transit system connecting the main train station to the main destination areas of the city. In the context of those deliberations, they have commissioned the development of a virtual Uppsala overlaid with one possible PRT deployment. The model is fully interactive and consists of structural (buildings, roads, etc.) and dynamic (traffic, pedestrians) aspects.

During the 4 years that we have been involved with this project, we have observed the role that the virtual city has played in the evolution of the conversations between the stakeholders. Whereas in the beginning the PRT system was the object of technical and operational concerns, over time, and partly due to their interactions with the virtual model, those concerns disappeared. Towards the end, the concerns of the stakeholders shifted towards the design of the tracks and stations, and how to better blend them with the city. We observed that the artifact in itself would probably be of very little value, had we not have a dedicated person in place for exercising it during stakeholders meetings. Finally, we also observed that the fact that the model was online and changeable during meetings had a strong positive effect on the stakeholders' engagement with the virtual city, and on their decision to support further efforts to gather political support for the PRT system at the county level. The virtual city is now starting to serve as a common operating picture for urban design.

This case study is just one data point and should not be used to draw general conclusions regarding the role of virtual cities in urban planning. We hope our experience reported here can be reproduced by others so to gather additional evidence on the benefits of virtual reality in sustainable urban planning.

Acknowledgments

The authors would like to thank everyone involved in the Uppsala city virtualization project, specifically: Ron Swenson, Michael Cerquoni, Bengt Gustafsson, Lorraine Kan, Anton Popov, Orly Onofre, Charly Deschizeaux, and Nerds 'n Squares. The City of Uppsala, the County Academic Hospital and the facilities manager of the University of Uppsala commissioned this project. The large OpenSimulator and Second Life viewers community is a striking example of a healthy and vibrant bottom-up effort for the common good; without their contributions to those open source projects, this work would not have been possible. The data and observations for this case study have been partially supported by a grant from the National Science Foundation IIS-0808783.

Referenced Websites

Site 1: Youtube Encitra channel
http://www.youtube.com/user/encitravideos

Site 2: The OpenSimulator Project
http://opensimulator.org

Site 3: Second Life 3rd Party Viewers
http://wiki.secondlife.com/wiki/Third_Party_Viewer_Directory

Site 4: Amazon Web Services, Elastic Computing Cloud
http://aws.amazon.com/ec2/

Site 5: Imprudence/Kokua viewer
http://kokuaviewer.org

Site 6: Zen Viewer
https://bitbucket.org/Zena_Juran/zen-viewer

Site 7: AutoDesk Maya
http://www.autodesk.com/maya/

Site 8: ArchVirtual
http://archvirtual.com/

Site 9: SimGIS
http://blog.simgis.com/

Site 10: SLGIS
http://slgis.org/

Site 11: UrbanSim
http://www.urbansim.org

References

[1] N. Abercrombie, S. Hill, and B. S. Turner, Dictionary of Sociology. Harmondsworth, UK: Penguin, 2006.
[2] T. Bakıcı, E. Almirrall, and J. Wareham, A Smart City Initiative: the Case of Barcelona, Journal of the Knowledge Economy, vol. 3, no. 1868-7865, pp. 1-14, 2012.
[3] P. Baudisch, N Good, and P. Stewart, focus plus context screens: Combining display technology with visualization techniques, Proceedings of the 14th annual ACM symposium on User Interface Software and Technology, Orlando, Florida, Sponsored by ACM SIGGRAPH and SIGCHI, 2001, pp. 31-40.
[4] M. Behrisch, L. Bieker, J. Erdmann, and D. Karjzewicz, SUMO - Simulation of Urban Mobility -- an Overview, Proceedings of 3rd International Conference on Advances in System Simulation, Barcelona, España, 2011, pp. 63-68.
[5] V. Bourdakis, Virtual Reality: A Communication Tool for Urban Planning, CAAD Towards New Design Conventions (A. Asanowicz and A. Jakimowitz, Eds.). Białystok, Poland: Technical University of Bialystok, 1997, pp. 45-59.
[6] D. Carter, Urban Regeneration, Digital Development Strategies and the Knowledge Economy: Manchester Case Study, Journal of the Knowledge Economy, vol. 3, no. 2, pp. 1-21, 2012.
[7] D. Chowdhury, L. Santen, and A. Schadschneider, Statistical Physics of Vehicular Traffic and Some Related Systems, Physics Reports, vol. 329, no. 4-6, pp. 199-329, 2000.
[8] W. D. Cottrell, Critical Review of the Personal Rapid Transit Literature, Proceedings of the 10th International Conference on Automated People Movers, Florida, 2005, pp. 1-14.
[9] M. Dodge, S. Doyle, A. Hudson-Smith, and S. Fleetwood, Towards the Virtual City: VR & Internet GIS for Urban Planning, In Proceedings of Virtual Reality and Geographical Information Systems Workshop, London, 1998.
[10] J. Döllner, T. Kolbe, F. Liecke, T. Sgouros, and K. Teichmann, The Virtual 3D City Model of Berlin-Managing, Integrating, and Communicating Complex Urban Information, Proceedings of the 25th Urban Data Management Symposium UDMS, Denmark, 2006, pp. 1-12.
[11] B. Flyvbjerg, Case Study, The Sage Handbook of Qualitative Research, 4th Edition (N. K. Denzin and Y. S. Lincoln, Eds.). Thousand Oaks, CA: Sage, 2011, pp. 301-316.
[12] R. Gilbert and A. Perl, Grid-Connected Vehicles as the Core of Future Land-Based Transport Systems, Energy Policy, vol. 35, no. 5, pp. 3053-3060, 2007.
[13] B. Glaser and A. Strauss, The Discovery of Grounded Theory: Strategies for Qualitative Research. Chicago, IL: Aldine Publishing Co, 1967.
[14] H. Hielkema and P. Hongisto, Developing the Helsinki Smart City: The Role of Competitions for Open Data Applications, Journal of the Knowledge Economy, vol. 3, no. 2, pp. 1-15, 2012.
[15] B. Huang, B. Jiang, and H. Li, An integration of GIS, virtual reality and the Internet for visualization, analysis and exploration of spatial data, International Journal of Geographical Information Science, vol. 15, no. 5 , pp. 439-456, 2001.
[16] J.H. Irving, H. Bernstein, C. L. Olson, and J. Buyan, Fundamentals of personal rapid transit, Lexington: Lanham, 1978.

[17] Toni Ishida, Jun-ichi Akahani, Kaoru Hiramatsu, Katherine Isbister, Stefan Lisowski, Hideyuki Nakanishi, Masayuki Okamoto, Yasuhiko Miyazaki, and Ken Tsutsuguchi, Digital city kyoto: towards a social information infrastructure, in Proceedings of the 3rd international conference on Cooperative information agents III (CIA'99), Berlin, Heidelberg, 1999, pp. 34-46.

[18] D. Koller, P. Lindstrom, W. Ribarsky, L. Hodges, N. Faust, and G. Turner, Virtual GIS: A Real-Time 3D Geographic Information System, Proceedings of the 6th conference on Visualization, Washington,1995, pp. 94.

[19] N. Komninos, M. Pallot, and H. Schaffers (eds.), Special Issue on Smart Cities and the Future Internet in Europe, Journal of the Knowledge Economy, Springer US, vol. 3, pp. 1-16, February 2012.

[20] N. Komninos and P. Tsarchopoulos, Toward Intelligent Thessaloniki: from an Agglomeration of Apps to Smart Districts, Journal of the Knowledge Economy, Springer US, vol. 3, pp. 1-20, February 2012.

[21] A. Kornhauser, A quantitative analysis of synchronous vs. quasi-synchronous network operations of automated transit systems, Transportation Research, vol. 9, no. 4, pp 241-248, 1975.

[22] S. Lee, South Korea: From the Land of Morning Calm to ICT Hotbed, The Academy of Management Executive, vol. 17, no. 2, pp. 7-18, 2003.

[23] S. Lee, T. Yigitcanlar, J. Han, and Y. Leem, Ubiquitous urban infrastructure: Infrastructure planning and development in Korea, Innovation: Management, Policy & Practice, vol. 10, no. 2-3, pp 282-292, 2008.

[24] C. Lopes, L. Kan, A. Popov, and R. Morla, PRT Simulation in an Immersive Virtual World, Proceedings of First International Conference on Simulation Tools and Techniques for Communications. Marseilles, France. Networks and Systems (SIMUTools), 2008, pp. 1-7.

[25] C. Lopes, The Massification of Systems Modeling and Simulation with Virtual Worlds, In Proceedings of 7th joint meeting of the European Software Engineering Conference (ESEC) and the ACM SIGSOFT Symposium on the Foundations of Software Engineering (FSE), New York, 2009, pp. 63-70.

[26] D. MacKinnon, High Capacity Personal Rapid Transit System Developments, IEEE Transactions on Vehicular Technology, vol. 24, no. 1, pp. 8-14, 1975.

[27] K. Muller and S. Sgouris, Simulation-based Analysis of Personal Rapid Transit Systems: Service and energy Performace Assessment of the Masdar City PRT Case, Journal of Advanced Transportation, vol. 54, no. 4, pp. 2042-3195, 2011.

[28] A. Nader, Paths to a low-carbon economy - The Masdar example, Energy Procedia, vol. 1, no. 1 , pp. 3951-3958, 2009.

[29] C. Ratti and A. Townsend, The Social Nexus, Scientific American, vol. 305, pp. 42-48, August 2011.

[30] D. Reiche, Renewable Energy Policies in the Gulf countries: A case study of the carbon-neutral *MasdarCity* in Abu Dhabi, Energy Policy, vol. 38, no. 1, pp. 378-382, 2010.

[31] T. Sarjakoski, Networked GIS for public participation - emphasis on utilizing image data, Computers, Environments and urban systems, vol. 22, no. 4, pp. 381-392, 1998.

[32] H. Schaffers, N. Komninos, M. Pallot, B. Trousse, M. Nilsson, and A. Oliveira, Smart Cities and the Future Internet: Towards Cooperation Frameworks for Open Innovation, In The Future Internet, Berlin: Springer-Verlang, 2011, pp. 431-446.

[33] F. Steinicke, T. Ropinski, K. Hinrichs, and J. Mensmann, Urban city planning in semi-immersive virtual reality systems, Proceedings of the First International Conference on Computer Graphics Theory and Applications, Setúbal, Portugal, 2006, pp. 192-199.

[34] G. Tegnér, M. Hunhammar, I. Andrésson, J-E. Nowacki, and K. Dahlström, PRT in Sweden: From Feasibility Studies to Public Awareness, in proceedings of the 11th International Conference on Automated People Movers, Vienna, 2007, pp. 1-20.

[35] G. Tegnér and E. Strömblad, Report on the Uppsala Boländerna PRT feasibility study, European Commision DG Research, 6th Framework Programme, Thematic Priority 1.6, Contract Nr. 031315, 2010.

[36] E. Thompson, M. Horne, S. Lockley, and M. Cerny, Towards an Information Rich 3D City Model: Virtual NewcastleGateshead GIS Integration, in Proceedings of 12th International Conference on Computers in Urban Planning and Urban Management, ALBERTA, Canada, 2011.

[37] C. Vanegas, D. Aliaga, B. Benes, and P. Waddell, Interactive Design of Urban Spaces using Geometrical and Behavioral Modeling, ACM Transactions on Graphics, vol. 28, no. 5, pp. 111:1--111:10 ,2009.

[38] V. R. Vuchic, Personal Rapid Transit: An Unrealistic System, Urban Transportation International (Paris), no. 7, September/October, pp. 35, 1996.

[39] S. Young, R. Miller, and D. Landman, Automated People Mover on a University Campus: Mobility Impact Analysis, Transportation Research Record: Journal of the Transportation Research Board, vol. 1872, pp. 56-61, January 2004.