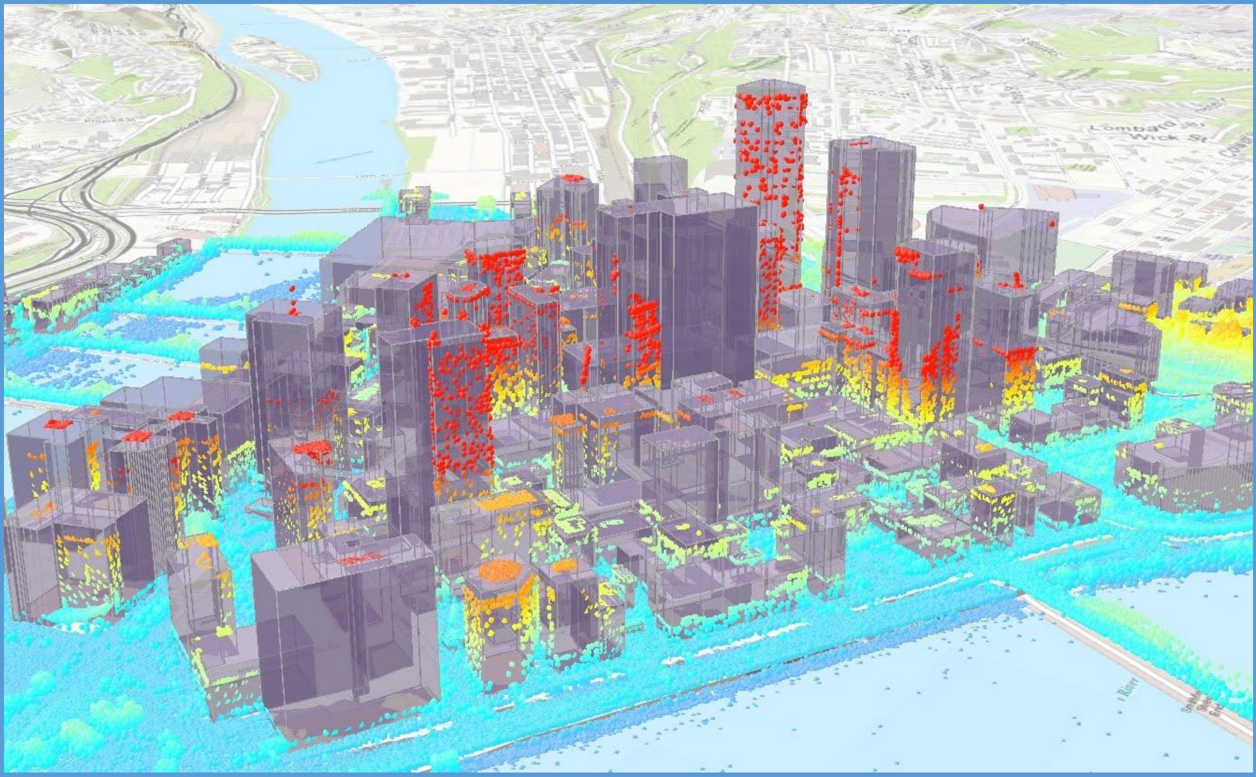

3D/Data Visualization for Urban Design and Planning

A Collaborative Research Project Between Carnegie Mellon University and the City of Pittsburgh

March 2019

Remaking Cities Institute
School of Architecture, Carnegie Mellon University

Disclaimer

Contents

Acknowledgements

Led by the Remaking Cities Institute in the School of Architecture, Carnegie Mellon University (CMU), this research, conducted in Pittsburgh Pennsylvania, USA, has been a collaboration between the City of Pittsburgh Department of City Planning and CMU's School of Architecture (College of Fine Arts), Heinz College of Information Systems and Public Policy, Entertainment Technology Center, and School of Design (College of Fine Arts). The research team would like to thank all who made this project possible.

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1. OVERVIEW

In the coming decades, American cities will increasingly rely on computational systems to improve many aspects of urban life. Distributed networks of sensors and networked computation will be fundamental technologies for achieving important civic goals, such as increasing the efficiency of using and maintaining city infrastructure, streamlining city operations and decision-making, improving public health and safety, and monitoring the environmental and social conditions of urban life. The term “Smart City” has emerged to describe these systems.

In August of 2014, the City of Pittsburgh and Carnegie Mellon University (CMU) entered into a Memorandum of Understanding that outlined a City/CMU partnership (Metro21) for research, development and deployment of new technologies using Pittsburgh as an urban laboratory.

In 2015, the CMU Remaking Cities Institute (RCI), GIS software company Environmental Systems Research Institute (Esri, Inc.), and Pittsburgh-based educational gaming company Simcoach Games teamed with the City of Pittsburgh Department of City Planning to produce a 3D digital model of Smithfield Street in downtown Pittsburgh that illustrated the potential for 3D simulation tied directly to building and infrastructure performance. While the simulation provided realistic visualization and animation, the interactive interface for a data dashboard that accompanied the visualization was more of a choreographed presentation to communicate what was possible, an “idea in the making,” not a working application.

In 2016, RCI received funding from the Deloitte Foundation and The Heinz Endowments to research and test existing 3D visualization programs for urban design and city planning, such as Geographic Information System (GIS), Building Information Modeling (BIM), and 3D simulation programs. Three applications of the software programs were investigated: 1) to analyze potential and proposed development projects; 2) to test zoning and urban design regulations; and 3) to determine capacity of city infrastructure. The primary research goal was to select the most appropriate 3D programs for the Pittsburgh Department of City Planning for everyday use. A second goal was to publish the results of the research for the use of planning departments in other cities, private consultants, real estate developers, academics, and researchers.

A significant challenge of the study was to demonstrate how to communicate design scenarios and abstract data to elected officials, private developers, academic institutes, and citizens using 3D visualization tools.

The research team was led by the Remaking Cities Institute and included four other CMU entities: School of Architecture, Heinz College, School of Design, and the Entertainment Technology Center. Phase I, funded by the Deloitte Foundation, benchmarked and documented existing 3D software programs. Phase II, funded by The Heinz Endowments, used software selected from Phase I to develop an interactive virtual reality (VR) design tool that could be used by city planning departments. Phase III, also funded by The Heinz Endowments, tested the modeling, visualization, and communications software on an urban development corridor project in Pittsburgh. Supplemental funding was provided by the CMU Metro21 program to produce a beta website to operationalize the 3D visualization technology for public communications.

Below are brief summaries of the sections of the report.

Section 2 (Background) traces CMU's roots in 3D computer simulation and the events leading to this research project.

Section 3 (Phase I Research Summary) documents and reviews over thirty off-the-shelf 3D software programs for modeling and representation applications. Interviews were conducted with city planning departments, universities, urban design and planning firms, and software firms.

Section 4 (Phase II Research Summary) describes work by students and faculty in the CMU Entertainment Technology Center graduate program. Virtual reality (VR) technologies were used as planning tools to demonstrate how VR technology could create a sense of place for an urban development corridor selected by the Pittsburgh Department of City Planning. Additionally, various UI/UX (User Interface/User Experience) techniques were developed to test on-the-fly design changes (by guests in the VR experience) and how that might impact "sense of place."

Section 5 (Phase III Research Summary) describes work by graduate students and faculty in the CMU Master of Urban Design program. Through a progressive series of design assignments for the same urban development corridor as in Phase II, the students first tested geospatial software and then advanced to 3D modeling, visualization software, and VR software.

Section 6 (Public Communications Research Summary) describes development by students and faculty of the CMU School of Design of a beta website for planning department public communications utilizing 3D material.

Section 7 (Literature Research) traces the rise of 3D visualization from the development of Building Information Management (BIM) software to augmented reality and virtual reality and discusses the appropriate use of 2D or 3D visualization tools.

Section 8 (Software Research for City Planning) describes the types of planning tasks performed by city planning departments, their suitability for 3D application, the criteria used by the research team to select off-the-shelf 3D software for testing, and descriptions of the specific software determined to be particularly useful for city planning departments.

Section 9 (Research Findings) discusses the 3D software challenges confronting city planners and urban designers. Topics include adoption of 3D software by planning departments, 3D as a working and communications tool, VR as a design tool, realistic simulation, and incompatibility of software platforms.

Section 10 (Software Interoperability and Workflows) presents a practical guide for city planners to work with the tested 3D software and to use it to communicate with the public. A workflow diagram was developed by the research team that links the tested software (and platforms) to accomplish typical planning and urban design tasks

Section 11 (Recommendations and Future Needs) describes practical recommendations for 3D visualization software for everyday practice of city planning departments and urban design firms, and how developers and universities can assist in that effort. The section ends with expectations for near and long-term 3D software development.

The CMU research team faculty foresees that 3D software will soon improve its ability to document context and in developing expanded and higher quality libraries of realistic objects and textures for importing into design models. VR and real-time graphics are forecasted to be the next “new wave” of innovation with the ability of inserting models of buildings and public spaces into “real” contexts. This is now happening in gaming, the industry leader in these software advances.

For city planning tasks, location-based geospatial platforms (GIS) currently offer the greatest potential for both geospatial and 3D modeling compatibility. The GIS platform is now capable of real-time design and modeling (e.g. buildings and other design objects) when the 3D model is created within the GIS platform. This is not now possible with other 3D non-GIS modeling software. Future geospatial software development likely will focus on the commercialization of 3D software tools specifically developed for city planning departments, urban design firms, and university urban design programs.

2. BACKGROUND

In the spring of 2015, the City of Pittsburgh and The Heinz Endowments established the first annual p4 Summit whose focus was “People, Planet, Place, and Performance”. The p4 initiative’s intent was to build upon Pittsburgh’s global and local relationships with cities, architects, planners, and universities to create innovative approaches to urban development and design, architecture, and employment for the citizens of Pittsburgh. In collaboration with colleagues in European cities, especially those with industrial pasts, community leaders sought to describe and define transformational sustainability practices to create a green and healthy environment and build an inclusive economy.

A team of architecture faculty at Carnegie Mellon University and the Remaking Cities Institute (RCI) were asked to create a physical three-dimensional model of the city for the p4 conference that would help define the performance measure “Place”, in particular promoting innovation in urban design. The architecture faculty quickly determined that a 3D digital model rather than a physical model would be more effective for meeting The Heinz Endowment’s agenda for the p4 Conference.

Why was CMU involved? In the previous summer of 2014, CMU and the City of Pittsburgh launched Metro21, an initiative devoted to enriching the University’s research and development capabilities to address challenges faced by Pittsburgh and its surrounding metropolitan region. Metro21 roots can be found in Traffic21, a CMU institute created in 2009 with the support of Pittsburgh businessman, civic leader, and philanthropist, Henry Hillman. Hillman, who allegedly waited in the early morning for traffic signals to change in the Oakland neighborhood where there were no other vehicles, suggested that the groundbreaking transportation research that was being developed at CMU use the City of Pittsburgh as a “real-world” partner to deploy projects and test solutions. Based on that success, Metro21 recently created the MetroLab Network, a national city-university collaboration for urban innovation of over forty US cities and fifty universities. Like Traffic21 and Metro21, MetroLab partners focus on research, development, and deployment (RD&D) projects that offer technological and analytically-based solutions to challenges facing urban areas including: inequality in income, health, mobility, security and opportunity; aging infrastructure; and environmental sustainability and resiliency.[1]

The roots of CMU innovation in urban design can be traced to the establishment in 1963 of the Urban Laboratory in the School of Architecture by David Lewis. It was one of the first educational programs in urban design in the world where students worked hands-on with elected officials, agency representatives, and citizens. Students completed urban design projects for communities in the Pittsburgh metropolitan region. In 1964, Lewis and Raymond Gindroz founded Urban Design Associates (UDA) one of the earliest architecture firms in the US to concentrate on the urban design of neighborhoods and cities. Lewis and Gindroz pioneered methods for engaging citizens in the design of community centers, schools and neighborhoods. The firm, known for refining and developing the public planning process, authored "The Urban Design Handbook, Techniques and Working Methods." [2]

In addition to innovation in urban design, the CMU School of Architecture, whose slogan is "Where Art and Technology Meet Practice," has deep roots in computational design and 3D technologies. In the 1960s and 1970s faculty members Charles Eastman and Ömer Akin were pioneers in computer design, writing articles about its educational and professional uses. They also started a Ph.D. program in the new science of Computer Aided Design (CAD). In the early 1970s Volker Hartkopf further broadened the post-graduate program offering courses in Building Science and Computational Design. [3] The curriculum, advanced degrees, and research in the School of Architecture continue to be on the cutting edge of innovation, sustainability and technology.

A third CMU-related entity identified as innovative users of 3D was the Institute of Robotics of the School of Computer Science. Professor Stephen Smith and his colleagues had been using 3D models of Pittsburgh in their work with Surtrac (Scalable URban TRAffic Control), an innovative approach to real-time traffic signal control that combines artificial intelligence research and traffic flow theory. Surtrac optimizes the performance of traffic signals and improves traffic flow by reducing congestion resulting in: reduced waiting times; shorter trips; less pollution; and happier drivers. A pilot project in the East Liberty neighborhood of Pittsburgh showed that, by using sensors and algorithms to optimize traffic flow, vehicles spent forty percent less time idling, and automobile emissions reduced by 21 percent. [4]

Figure 2.1 – Traffic simulation 3D model, Downtown Pittsburgh, courtesy of Surtrac

In the spirit of collaborative and interdisciplinary work, the architecture faculty team sought researchers in other CMU departments with expertise in 3D visualization. The Entertainment Technology Center (ETC), co-founded by Don Marinelli, a Professor of Drama, and Randy Pausch, a Professor of Computer Science, and established in 1999, was identified because of its innovative work with gaming and virtual reality software. ETC faculty and students work in interdisciplinary teams of artists and technologists on entertainment and for-purpose challenge projects such as interactive exhibits, theme park designs, and the creation of video games for external clients. Since the inception of the ETC, augmented and virtual reality tools have been frequent delivery components of projects. Simcoach Games, a company spun out of the ETC to use gaming technologies and solve real-world problems, was also identified as a project collaborator because of their work with the Port Authority of Allegheny County on the Bus Rapid Transit (BRT) project. The Port Authority commissioned Simcoach Games to develop an interactive tool to obtain public input about the location and design of proposed BRT stations. The team then reached out to the Pittsburgh Department of City Planning as a partner and also to Esri, Inc. a global leader in GIS software, for technical assistance.

Figure 2.2 – Bus Rapid Transit interactive simulation game, courtesy of Simcoach Games

As its first task the research team created an accurate and 3D digital model of all of the City of Pittsburgh's built environment as a base for later simulation.

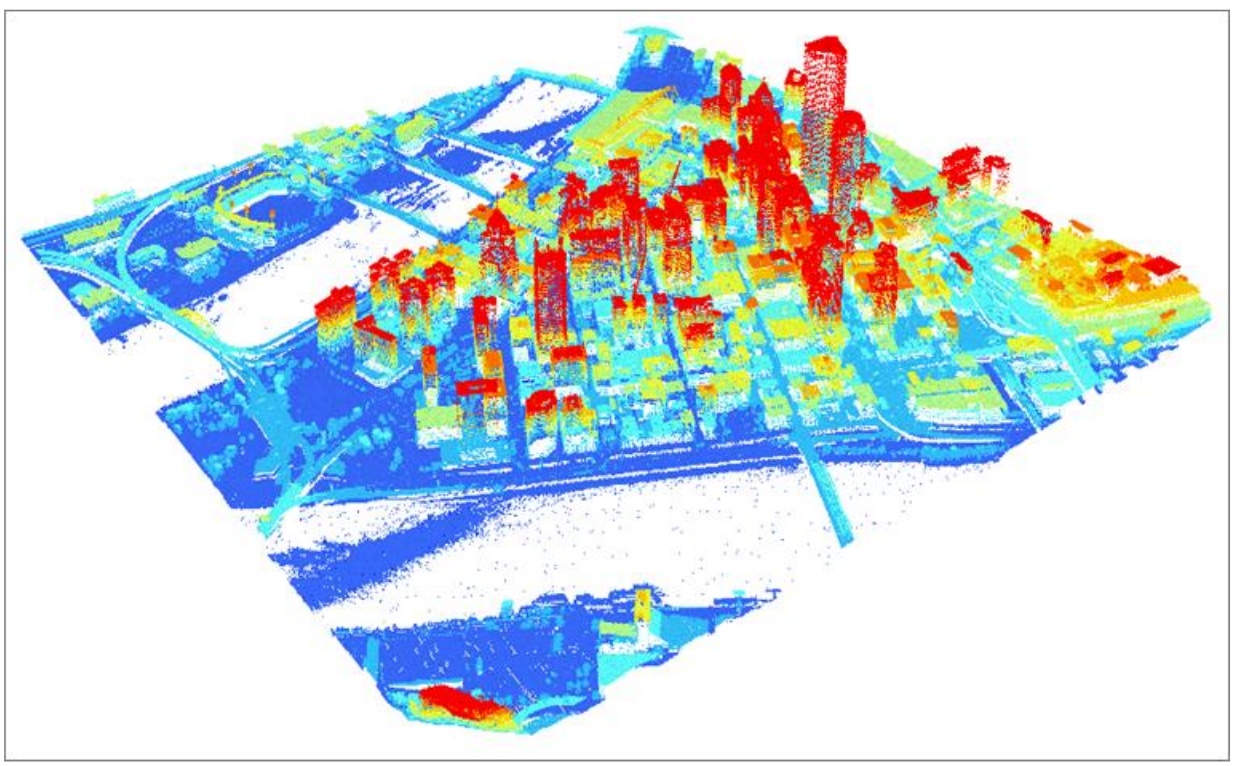


Figure 2.3 – Original model created using lidar data, created by CMU students and faculty

The 3D model was then used by CMU students in a spring 2015 Master of Urban Design studio. The studio project produced three urban design scenarios for a multi-modal street reconfiguration project of Smithfield Street in downtown Pittsburgh. Animated digital 3D depictions were created for each scenario using CityEngine (Esri, Inc.) software and Unity (Unity Technologies) software. The project demonstrated that 3D visualization is a more effective design tool than a static physical model and also a better communications tool for communicating complex urban design scenarios.

Figure 2.4 – CityEngine model created by Patrick Gahagan of Esri, Inc. and CMU Students

The research team presented the 3D model and three student urban design scenarios at the p4 Conference to demonstrate how 3D simulation, combined with other analysis tools, could measure the physical, environmental, and economic impacts of urban design and infrastructure changes in real-time.

Figure 2.5 – Unity scene created by Simcoach Games

The p4 video can be found at the link below.

http://www.p4pittsburgh.org/pages/ray-gastil-planning-director-city-of-pittsburgh

After the p4 Conference, the Remaking Cities Institute pursued funding for joint research projects with the CMU School of Computer Science and the Robotics Institute to further study the potential of the p4 simulation model. While no 3D projects were funded, the Surtrac team of the Robotics Institute incorporated air quality sensing devices into its traffic signalization program that demonstrated the capability of multiple uses of digital technology.

The RCI and Heinz College research team, not wanting to lose momentum, sought funding to investigate further the potential for 3D visualization for urban design and city planning. The decision was made not to create new software but to research and test existing 3D visualization programs. A four-phased research project was proposed and accepted for funding. **Phase I** would benchmark and document existing 3D software programs. **Phase II** would add virtual reality (VR) programs to the mix. **Phase III** would test the 3D and VR programs in an urban design project in Pittsburgh. **Phase IV** would document the findings.

Phase I was funded by the Deloitte Foundation. Phases II, III, and IV were funded by the Heinz Endowments. At the suggestion of The Heinz Endowments for also addressing 3D visualization's potential as a communications tool, supplemental funding was provided by the CMU Metro21 Institute for the development of a beta website to operationalize the 3D visualization technology for public communications.

A major goal of the 3D visualization study was to recommend the most appropriate 3D program (or programs) and workflows for the City of Pittsburgh Department of City Planning and to publish the results of the research for the use of other city planning departments, private consultants, developers, academics, and researchers.

A significant challenge was to demonstrate how to visually communicate both abstract and tangible data using design scenarios to allow urban planners and designers to make informed decisions and to communicate designs effectively with stakeholders. Stakeholders include elected officials, private developers, academic institutes, and citizens who would be impacted by development.

References

[1] MetroLab Network, http://metrolab.heinz.cmu.edu/

[2] https://en.wikipedia.org/wiki/Urban_Design_Associates

[3] Carnegie Mellon University Archives, Official University Records, Architecture Department, Records, 1905-1990, https://libwebspace.library.cmu.edu/libraries-and-collections/Archives/UnivArchives/ArchitectureDepartment.html

[4] Surtrac: Real-Time Adaptive Traffic Signal Control for Urban Road Networks, Intelligent Coordination and Logistics Laboratory, August 2012, http://icll.ri.cmu.edu/projects/traffic/

3. PHASE I RESEARCH SUMMARY

Research and Benchmarking (Summer 2017)
Funded by the Deloitte Foundation

Phase I involved three CMU graduate students: two from the Heinz College (one Information Systems student and one Public Policy and Management student) and one Master of Urban Design student from the School of Architecture, who were directed by two faculty of RCI research faculty team. In addition to their paid work during the summer of 2017, the students, known as Deloitte Fellows, each received $12,000 scholarships for the fall 2017 semester. The Deloitte Fellows researched 3D software and technologies to create a knowledge base for Phases II and III.

The Fellows conducted global online research of existing 3D modeling and visualization programs and interviewed users of the major software applications. They reached out to over 300 city planning departments, universities, and architecture/design firms across the world. They conducted 57 one-on-one telephone interviews with urban planners, architects, professors, GIS professionals, and software companies. From this research the Fellows developed a list of 31 viable and relevant software programs, plugins, and extensions with 3D visualization capabilities and built an interactive, online filtered database listing attributes of each software program.

Software Matrix

Phase I reserach was conducted in summer 2017, all the information and content were collected through interviews from June to Augest, 2017. As such, all software listed in the alphabtically listed matrix were selected based on the usage of each software in architecture firms, city planning departments and universities.

Note: the table on this page is best viewed using Chrome, Safari, or Firefox browsers.

Software Name	CAD	BIM	GIS	Rendering	Animation	VR	AR	Other
3D Studio Max	✓			✓	✓	with Plugin	with Plugin	
ArcGIS Pro			✓					Point Cloud Data/ Photogrammetry
ArcGIS Online: 3D Scene Viewer			✓					
ArcGIS Online: Story Maps			✓					
AutoCAD	✓			✓				
Cesium								
CityEngine	✓		✓		✓			
CityPlanner	✓							
CyberCity								Point Cloud Data/ Photogrammetry
Enscape				✓	✓	✓	✓	
Infraworks	✓	✓	✓	✓	✓			

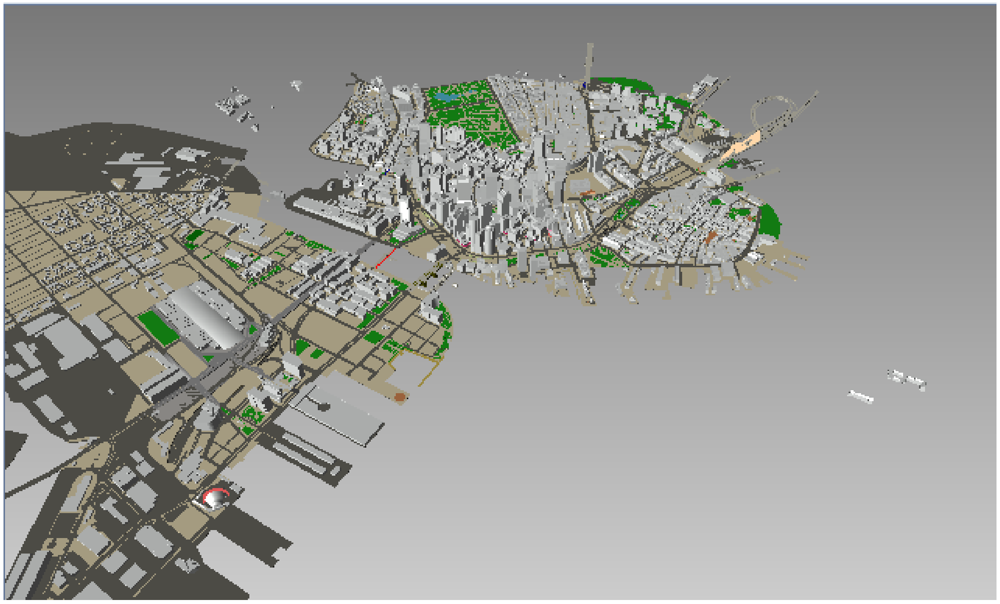
Figure 3.1 – Phase I Software Matrix

The full Software Matrix can be viewed at the link below.

https://sites.google.com/site/3ddatavisualizationresearch/project-definition

3D Visualization Examples >

ArcGIS Pro GIS 3D Model from 3D CAD Model Boston Planning and Development Agency



Source: CAD model of Downtown Boston. http://dwf.blogs.com/beyond_the_paper/2006/11/3d_dwf_files_de.html

The Boston Planning and Development Agency (BPDA) has been using a 3D model of the city since 2000. The Urban Design Technology Group has used several software over the years for maintaining the CAD model. Much of the model is a rough massing of the city, although certain areas have detailed texturing. Currently the Urban Design Technology Group uses 3D Studio Max to maintain this model. The model is divided into parcels that are available for download, allowing architects and developers to insert their plans within the context of the city. While this model has been excellent for visualization, it lacks accuracy and data integration. Because of specific ordinances regarding shadows on the Boston Commons, BPDA must conduct shadow studies, which are difficult with the CAD model.

In an effort to integrate data with the 3D model and increase analytical capabilities, the Office of Digital Cartography and GIS (ODCGIS) has been using ArcGIS Pro to create an updated GIS-based model. The office purchased buildings in strategic areas from CyberCity to complement the CAD model. The CAD buildings can be brought into ArcGIS Pro, but they appear as multiple files instead of a single building. To solve this problem, the ODCGIS first uses SketchUp to geolocate the building and dissolve the parts of the building into a single file. The office hopes that ArcGIS Pro will be better for conducting shadow studies and plans to update certain 2D maps with the 3D model.

This project used

- 3D Studio Max
- ArcGIS Pro
- CyberCity
- SketchUp

Link:
Urban Design Department, Boston Planning and Development Agency,
http://www.bostonplans.org/planning/urban-design

Figure 3.2 – Phase I 3D visualization example from conducted interview

Additional case studies can be found at the link below.

https://sites.google.com/site/3ddatavisualizationresearch/use-cases-scenarios

Three main themes emerged from the benchmarking research and interviews: 1) testing human-scale design in a 3D virtual world; 2) facilitating communication between professionals and the public; and 3) analytical capabilities. Following are representative examples of the use and value of 3D tools from cities, planning and urban design consultants, and universities.

Cities

Fort Collins, Colorado used a photo-realistic 3D model of their downtown area to evaluate options for building heights, massing, and setbacks as well as explore a range of building materials. 3D models facilitated communication between professionals and the public by increasing clarity in the development review process. City staff reported that community members initially had uninformed perspectives of a new development, whereas the 3D tool produced thoughtful and productive public discussion. "The challenge of balancing competing objectives will always remain—the tools may not result in consensus. Rather, they provide for more effective discussion of mutually understood aspects of a given proposal." [1] [2]

The **Miami Downtown Development Authority (MMDA)** uses 3D models to increase communication with the public. MMDA is an autonomous agency of the City of Miami dedicated to "promoting the economic health and vitality of Downtown Miami." [4] In the last decade, development in downtown Miami has increased substantially with developers building thousands of new residential units. This spike in development has led to an increase in density. [3] As more buildings appeared along Miami's downtown skyline, the MMDA began mapping them to keep residents and other potential developers informed. An interactive map utilized Story Maps (an Esri, Inc. application to describe proposals for new buildings); however, 2D maps failed to convey increased density. In response MMDA created a 3D model for a better representation of the quickly evolving Downtown. After finding that web hosting platforms were too heavy for their computers lacking a quality graphics card, MMDA decided to use an open-source JavaScript library of 3D globes and maps. It was light enough to run on their computers allowing them to host maps and upload new building proposals as they were submitted. They found that adding color and several 2D layers to the map made it a more useful tool.

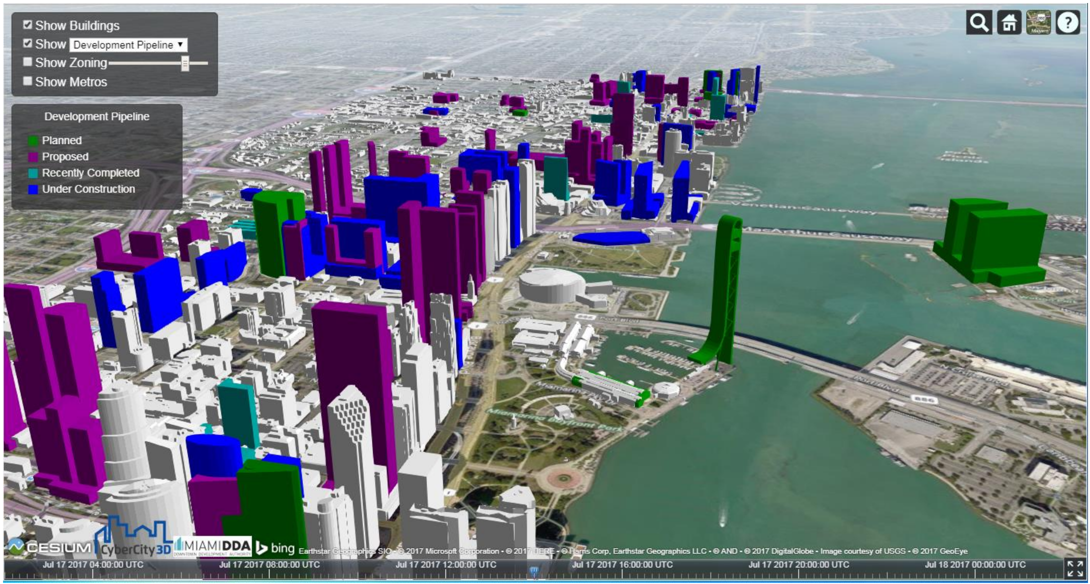


Figure 3.3 – Interactive 3D map of Downtown Miami

Source: http://cybercity3d.s3-website-us-east-1.amazonaws.com/?city=Miami

The **City of Miami Department of Planning & Zoning** recently adopted Zonar software developed by Zonar Systems to better visualize current and potential new zoning regulations. This software produces a 3D visualization that demonstrates what is possible to build on a designated parcel under the pertinent zoning regulations. The application is not used for designing buildings, but rather to demonstrate the maximum lot capacity in 3D. This web-based solution allows for easy interaction between city planners, commercial developers, and the public. The program includes 3D visualization, graphs, numerical data, and references to specific zoning code sections. The 3D visualization can be manipulated to show the consequences of rezoning and to review new development proposals. After city officials input the proposed measurements of the development proposal, the software will check the numbers against the requirements of the zoning regulations. The software review then can be exported as a printed report that details violations, if any.

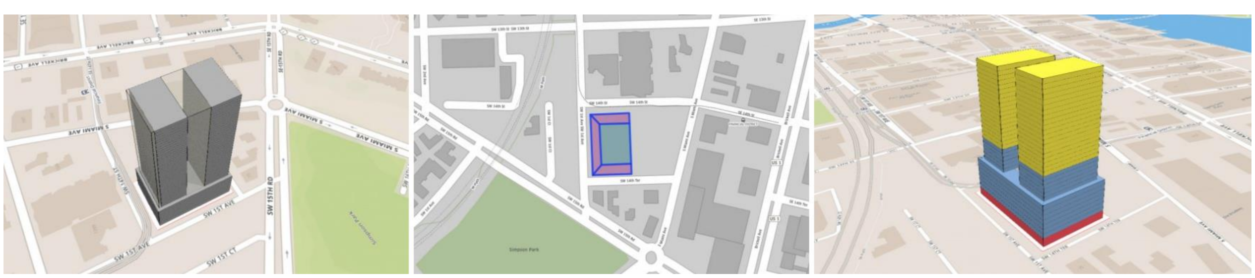


Figure 3.4 – Use of Zonar to visualize and analyze development proposals

Source: Zonar. https://www.zonar.city/case-study/broker-insight-better-insight-commercial-real-estate-brokers-and-their-clients

The **MetroGIS group at the Metro Government of Nashville & Davidson County** has experimented with a variety of software and technologies to better engage with the public. MetroGIS found that 3D visualizations produced more public feedback and consequently faster decisions. Modeling allows for easy depiction of zoning requirements and development proposals as well as the creation of videos and interactive visualizations. Using augmented reality, viewers can hover their smart phones over a 2D printout of the city and view a 3D model on their phone. Tapping the screen can switch between development scenarios. While less immersive than a virtual reality experience, this application requires only a smart phone not a headset. This reduces costs and allows easier interaction.

Figure 3.5 – Utilizing AR in Community Meetings - City of Nashville
(Photo Source: Micah Taylor)

The **City Philadelphia** used 3D Web Scenes (Esri, Inc.) to test urban planning scenarios by using the swipe view on the "redevelopment layer" to compare as-built and proposed buildings. This technology also gives users the ability to move through street scenes in 3D by turning on and off existing and proposed conditions, including shadow studies. Web Scenes images can be screen-captured and printed for public distribution to show important aspects of a project. [5]

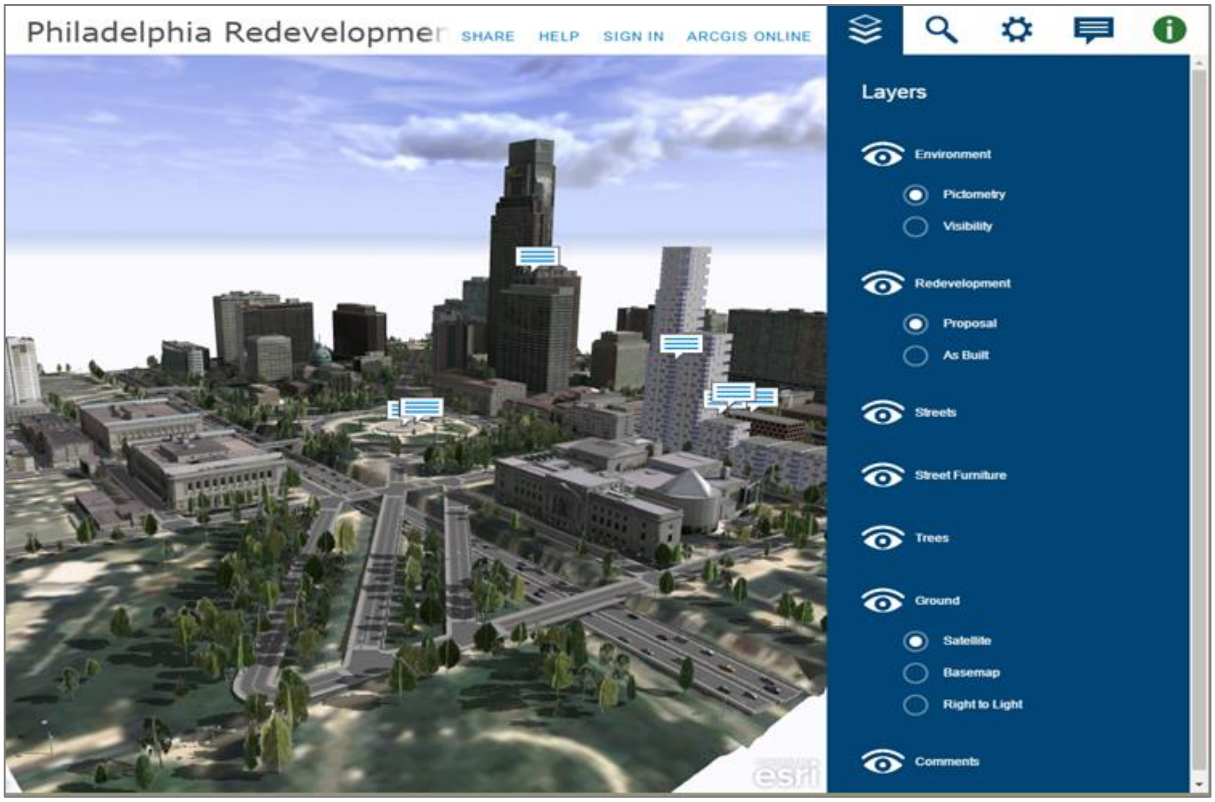


Figure 3.6 – City of Philadelphia Web Scene

The interactive Web Scene can be viewed at the link below.

http://www.arcgis.com/apps/CEWebViewer/viewer.html?3dWebScene=86f88285788a4c53bd3d5dde6b315dfe

Planning and Urban Design Consultants

Architecture and urban design firms are exploring the use of 3D visualization tools to improve their working processes and client interaction. **HKS**, an architecture firm based in Dallas, Texas, is developing scenario testing using 3D rendering and game engines. Designers are using real-time design feedback in virtual worlds to manipulate and evaluate design alternatives.

GGN, a landscape architecture firm in Seattle, Washington, utilizes VR technology to transition from the traditional 2D rendering world to the 3D virtual world. The studio uses a VR plugin to visualization models providing designers and clients with realism for the scale of the design.

LMN Architects of Seattle, Washington, uses 3D technologies for analysis and plug-in VR applications as visualization and communication tools to show designs to clients and edit features in real time

SOM, one of the world's largest architecture firms, does not have in-house standards for using 3D software. Instead they empower staff to experiment by not limiting them to particular software. In addition to technical drawings, SOM creates dynamic 3D visualizations (from photo realistic renderings to movies) using a variety of 2D and 3D software applications.

Universities

Leah Meisterlin of **Columbia University** studies the politics of spatial data analytics in planning. Her research indicates that current 2D mapping methods are not always decipherable by the public. Data maps can be poor communication and decision-making tools when engaging community members who lack map literacy skills.

Robert Schubert, Associate Dean for Research at the **Virginia Tech** School of Architecture and Urban Studies, notes that visualization cuts across all disciplines. When compared to a flat 2D image, 3D can be a more effective mode of communication and immersive virtual environments are more trusted because of their lower level of abstraction. Big data is driving change in urban areas and understanding and interpreting data is challenging using traditional spreadsheets. A well-integrated data processing platform helps the planning professional analyze 2D and 3D data more efficiently.

The **Carnegie Mellon University** School of Architecture Building Performance and Diagnostics faculty use 3D modeling as a planning & decision-making tool to analyze building energy use. Using city-owned buildings of the City of Pittsburgh, researchers Azizan Aziz and Vivian Loftness showed that energy consumption cost outpaced actual energy bills in municipal buildings. Data that can be used in a 3D model to help inform city staff to make policy changes includes energy use intensity (EUI - kBtu/sq. ft./year), the total amount of energy cost and GHG emission (mton/sq.ft.), and energy efficiency by building (similar to the Energy Star rating system).

In her Ph.D. thesis proposal, **Carnegie Mellon University** Ph.D. candidate Shalini Ramesh observed that in current urban planning and building design processes there is not one holistic and seamless approach to quantifying the thermodynamic interactions between the natural and the built environment. She attributed this to the separate and isolated use of microclimate simulation programs (Town Energy Balance model, ENVI-met, CitySim) and building energy simulation programs (EnergyPlus, eQUEST, TRNYS) and the absence of a design-decision- support platform to communicate and visualize the simulated results. [6] Ramesh demonstrated that data interoperability could build 3D urban scale models and establish requirements for accurate microclimate model setup using 3D GIS. In a case study of a twenty-eight acre site in the lower Hill District of Pittsburgh, Ramesh developed a visualization platform to communicate urban energy data for design decisions using a 3D web-based platform. By combining 3D maps with narrative text, images, multimedia content, and data tables, she demonstrated how online data sharing is a viable tool to contextualize geographic information and engage stakeholders at a neighborhood level. Click on the image below for a link to Shalini Ramesh's full dissertation.

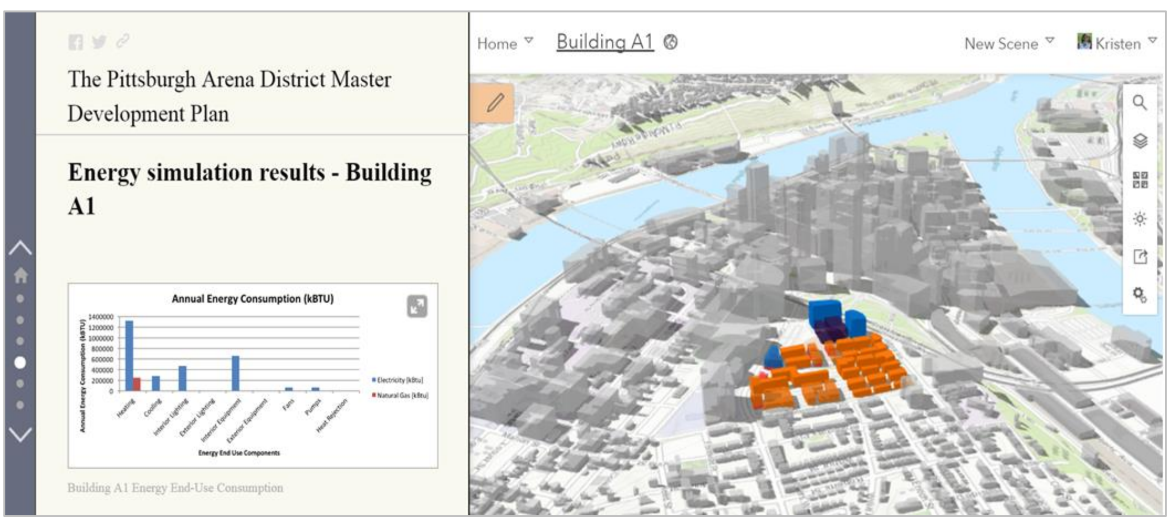


Figure 3.7 – Energy simulation data shown using Esri's Web Scenes and Story Maps

Full Documentation of Phase I

A link to the Deloitte Fellow's final presentation can be downloaded from the link below:

https://cmu.box.com/s/9ju6vnlqn6llcsw78v53iobpr944f8mj

Phase I documentation, including access to on-line software information, the Software Matrix, and 3D visualization examples is available at the link below.

https://sites.google.com/site/3ddatavisualizationresearch

References

[1]https://www.fcgov.com/planning/downtown/pdf/2017_0518_DowntownPlan_no_appendices_11x17_Web.pdf?1495140572, page 29

[2] 3D Basecamp 2016 – Cities & SketchUp: Planning for the future in 3D, https://www.youtube.com/watch?v=_k4WE_luWEs

[3] https://www.nytimes.com/2016/05/11/realestate/commercial/miami-emerges-from-gloom-into-residential-and-commercial-sunlight.html

[4] http://www.miamidda.com/About-DDA.aspx

[5] https://doc.arcgis.com/en/arcgis-online/reference/what-is-web-scene.htm

[6] "Urban Energy Information Modeling: A framework for quantifying and visualizing the thermodynamic interactions between the natural and the built environment affecting building energy consumption", Shalini Ramesh, School of Architecture, Carnegie Mellon University, February 2016

4. PHASE II RESEARCH SUMMARY

Virtual Reality Demonstration Project (Fall 2017)
Funded by The Heinz Endowments

Phase II involved graduate students in the "Digital District" project studio and faculty of the CMU Entertainment Technology Center (ETC) in a 3D demonstration project to investigate the combination of virtual reality technology and interactivity as planning tools. Faculty of the RCI study team and representatives of Pittsburgh City Planning participated with ETC on the project.

ETC students, including artists and programmers, built a VR application to explore how VR technology could create a sense of "Quality of Place." For example, they sought to demonstrate if VR is effective in communicating landscapes, physicality of environment, light, materials, sound, weather, and time of day in a public place, and whether useful information be collected from an audience that is immersed in the VR experience. ETC students addressed how VR (or other visualization technologies) could be used by urban designers to change or manipulate scenarios to communicate with design professionals and the public.

In their final deliverable the ETC students created a prototype tool for the HTC VIVE virtual reality system. The tool included a simulation of the Baum Boulevard corridor in Pittsburgh that included a suite of features to make changes to the urban design scenarios, and to preview and exhibit those changes under different parameters. For example, users could change the height and use of buildings and swap out street designs. Users could also view the broader neighborhood in miniature or full-scale, textured, or color-coded by zoning type. They could also set the weather and time of day to see how shadows and skylines would be affected and could take screenshots. The simulation was animated with moving pedestrians, cyclists, and cars. Environmental elements such as trees and street furniture provided realism.

Development of the interface for the VR tool was challenging as most of the target audience, urban planners and designers were expected to be unfamiliar with these technologies. Additionally, very few design standards exist yet for user interfaces in immersive virtual environments. The tool needed to be efficient, but also easy for a novice user to learn and navigate. The ETC team settled on an interface using the VIVE's handheld controllers that combined a dialed menu and pointing to control the experience. The dialed menu would be operated through and rendered around the controller touchpad allowing users to cycle through options and discover features at their own pace, limiting the number of options visible at any one moment to avoid overwhelming new users. The position and orientation of the controller itself was interpreted as a pointing gesture for the user to select, activate, and interact with objects in the 3D environment. A tutorial experience was included to walk new users through the control scheme and menu palette. Testing showed that while there was a brief learning curve, most users were able to learn the controls fairly quickly, and navigate through the scenarios.

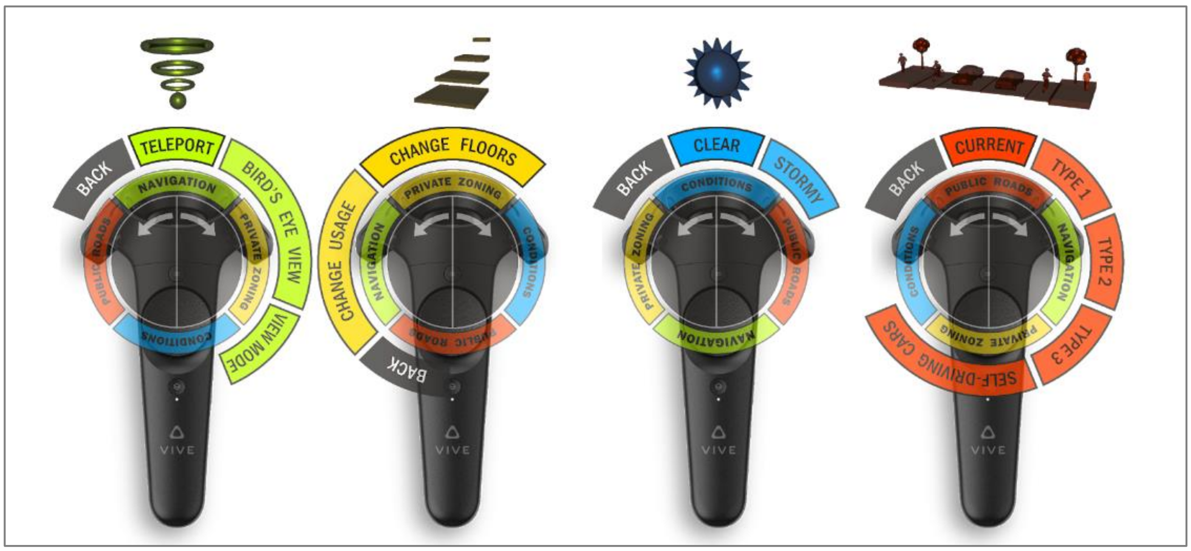


Figure 4.1 – Easy to use VR controls

An important lesson learned was that people have very different levels of comfort for immersion in virtual reality depending on their experience with VR. Adding ambient sound, even if not realistic, had an impact on ease and comfort of use, as did providing proper scale of projected objects. Photographic textures added familiar details. Programming the view aspect so that pedestrians and cars did not directly approach the viewer turned a possibly disconcerting experience to a pleasant one.

Figure 4.2 – Digital District demo examples

Full Documentation of Phase II

ETC students' Digital District demo video can be found on the link below.

https://youtu.be/rgfU9BNlz6g

Phase II documentation, including a summary of the project, the Digital District Team final presentation video, instructional manual with detailed user instruction on how to manipulate the functions of the handheld control, 3D art, design, programming, sign making, and UI documentation, and lessons learned is available at the link below.

https://sites.google.com/site/3ddatavisualizationresearch

5. PHASE III RESEARCH SUMMARY

3D Field Testing (Spring 2018)
Funded by The Heinz Endowments

Phase III was a team effort of the CMU Remaking Cities Institute, the CMU Entertainment Technology Center, the CMU School of Design, and the City of Pittsburgh Department of City Planning along with the studio projects of the Master of Urban Design (MUD) program in the CMU School of Architecture.

Ten 3D software programs from the Phase I research were selected by the research team for field testing by the MUD students. They represented four software types: 1) geospatial; 2) 3D modeling; 3) representation; and 4) virtual reality. All were deemed appropriate for every-day application by city planning departments. The students worked from personal laptops and from two gaming computers and Vive headsets for virtual reality testing and more complex software modeling. Coursework was supplemented by systems seminars conducted by faculty, software demonstrations and workflows conducted by the teaching assistant, seminars conducted by industry visitors, and a visit to the GeoDesign program at Jefferson University in Philadelphia, Pennsylvania.

Phase III continued the work developed in Phase II, but from a different perspective. Rather than developing a new software application, the studio focused on applying the ten software programs to communicating urban design alternatives for a specific site in the Baum Boulevard corridor selected by the City. Software testing was accomplished in sequential urban design projects. The first half of the semester focused on 2D GIS software to prepare background information and to analyze data. The initial projects provided an understanding of the urban systems that comprise the corridor's context and the planning software tools available to facilitate place-making designs and presentations. In later projects the students applied 3D platforms and modeling programs for street intersection designs and VR software for its experiential use as an urban design tool.

Figure 5.1 – Showcasing the final intersection design using a VR headset. Unity was used to create the VR demonstration.

The final project of the semester required integration of the software programs. The students valued the efficiency of CityEngine and the speed of real-time urban design modifications when working back-and-forth between CityEngine and Unity (model-to-VR). Drawbacks with 3D modeling platforms, such as Revit or SketchUp, included tedious application of textures to the 3D models and the inability to make real-time modifications in Unity VR. The utility of Story Maps lies with its ability to seamlessly add new information and linkages and its ability to accept real-time changes through its sharing capabilities, whereas its limited ability to hold large files, its delays in downloading Internet cloud content when making public and other presentations, and its lineal sequencing are drawbacks. The students determined that Web Scenes, although a useful presentation tool, was not a design tool and when pressed for time prioritized design time over testing another presentation tool.

Figure 5.2 – Three of the final seven intersection designs

There were several outcomes of the testing that were not software specific. Collaboration was the most significant issue for the students. Few of the design-oriented programs allowed file sharing. This was a problem as almost all the assignments were conducted by teams of two or the entire studio. Modeling multiple buildings for an urban setting, detailing basic massing-model form (adding textures), and geo-locating them into location-specific base maps or 3D sites is an arduous and time-consuming process. When using the typical go-to modeling platforms (Revit, Rhino, SketchUp) each building is a separate file void of geospatial information. 3D software, including both geospatial and 3D modeling platforms, are not collaborative tools. Design tasks are viewed by the software industry as a singular user experience, but urban designers and city planners typically practice and collaborate as teams. Realism was another issue. Modeling and representational software does not distinguish depth of field, is impervious to how a human eye visualizes settings, provides little orientation to scale, and is deficient at representing foreground framing of place and the public realm. Another issue was ease of use in a public meeting. Cloud-based software, while offering benefits of content choice, depth and breadth of information, numerous linkages, and a high degree of information management, is slow in real time and not well suited to communicating design ideas quickly and seamlessly in a civic engagement setting. The students and research team concluded that existing off-the-shelf 2D and 3D software, while useful for specific tasks by individual users, is currently less successful for collaborative design in teams and for public presentations -- the everyday work of city planners and urban designers.

Full Documentation of Phase III

Master of Urban Design students' final Story Map can be found at the link below.

https://carnegiemellon.maps.arcgis.com/apps/MapJournal/index.html?appid=13d712949cf349f0af42eb5683f1ac78

Phase III documentation, including a summary of the Urban Systems studio, a detailed description of the field testing, details of lessons learned from a field trip to Philadelphia and Jefferson University, software workflows, and student evaluations of software is available online at the link below.

https://sites.google.com/site/3ddatavisualizationresearch

6. PUBLIC COMMUNICATIONS RESEARCH

3D Visualization Technology for Public Communications (Spring and Summer 2018) Funded by Metro21

During this phase, researchers investigated technologies and approaches for a beta website to operationalize the 3D visualization technology for public communications. This portion of the project was conducted by a team from the Carnegie Mellon University School of Design, led by Assistant Teaching Professor Andrew Twigg, with additional work by Research Assistants Vikas Yadav (MDes), Marisa Lu (BDes), and Elizabeth Wang (BDes).

The team was brought onto the project for their experience with visual communication, digital interaction, web-based technologies, and 3D technologies in a Human Centered Design context.

Overview

Utilizing a combination of technology benchmarking, market research, and testing, the research group concluded that a viable set of technologies would marry the right mix of readily-available technologies and advanced but not leading-edge technologies to create a viable tool for public communication. This prototype utilizes these technologies:

- WordPress (PHP, MySql, HTML, CSS, Javascript/jQuery)
- Advanced Custom Fields plugin for Wordpress, which extends the explicit categories of information contained in a record for a single planning project
- Three.js for real-time 3D visualization

While the research team did not find an “ideal” solution to the problem, the above technologies can form a functional and future-ready platform as support for other technologies such as AR and VR become more viable.

Understanding the Landscape of Technology and Constituents

The initial research was focused on a handful of questions:

1. Identify available off-the-shelf technologies

a. The team identified a number of available technologies with some initial evaluation of these technologies:

General tech name	Company and/or Framework name	URL	View? Edit?	Pros	Cons
Blocks	Google	https://vr.google.com/blocks/	View	Easy to use, Immersive 3D perspective. Good for early prototyping	Precision modeling not currently available. Limited export ability
ARKit	Apple	https://developer.apple.com/arkit/	Both	Robust development environment	Requires special hardware which is usually expensive; Requires recent iOS device. iOS Deployment pipeline is complicated/restrictive
ARCore	Google	https://developers.google.com/ar/	Both	Robust development environment	Requires special hardware which is usually expensive; Requires recent Android device with certain hardware specifications, limited and expensive options
WebGL	threeJS	https://threejs.org/	Both	Very flexible and easier to build	Limitations on asset compression and rendering. Since its web based, experiences need active internet/Wi-Fi all the time
WebGL / WebVR	A-Frame	https://aframe.io/	Both	Simpler library of three.js	Limitations on asset compression and rendering. Since its web based, experiences need active internet/Wi-Fi all the time
WebGL	AR.js	https://medium.com/arjs	Both		Relatively older library Three.js / A-frame should be preferred over ar.js
Unity + Vuforia	Unity / Vuforia	https://library.vuforia.com/articles/Training/getting-started-with-vuforia-in-unity-2017-2-beta.html	Both	Can produce robust applications with elaborate experiences. Vuforia's marker based AR experiences are well touted in the industry.	Need to investigate more if Vuforia will support markerless AR experiences

Table 6.1 – Initial technology survey

2. Identify the stakeholders in a public planning process

a. Who would use these tools to prepare information for the public?

b. Who would be viewing information?

c. Using questions 2, 2.a, and 2b, and based on information from the full research team, the group created 10 personae for the users of the product, and mapped them to the project relative to their level of engagement and access to technology:

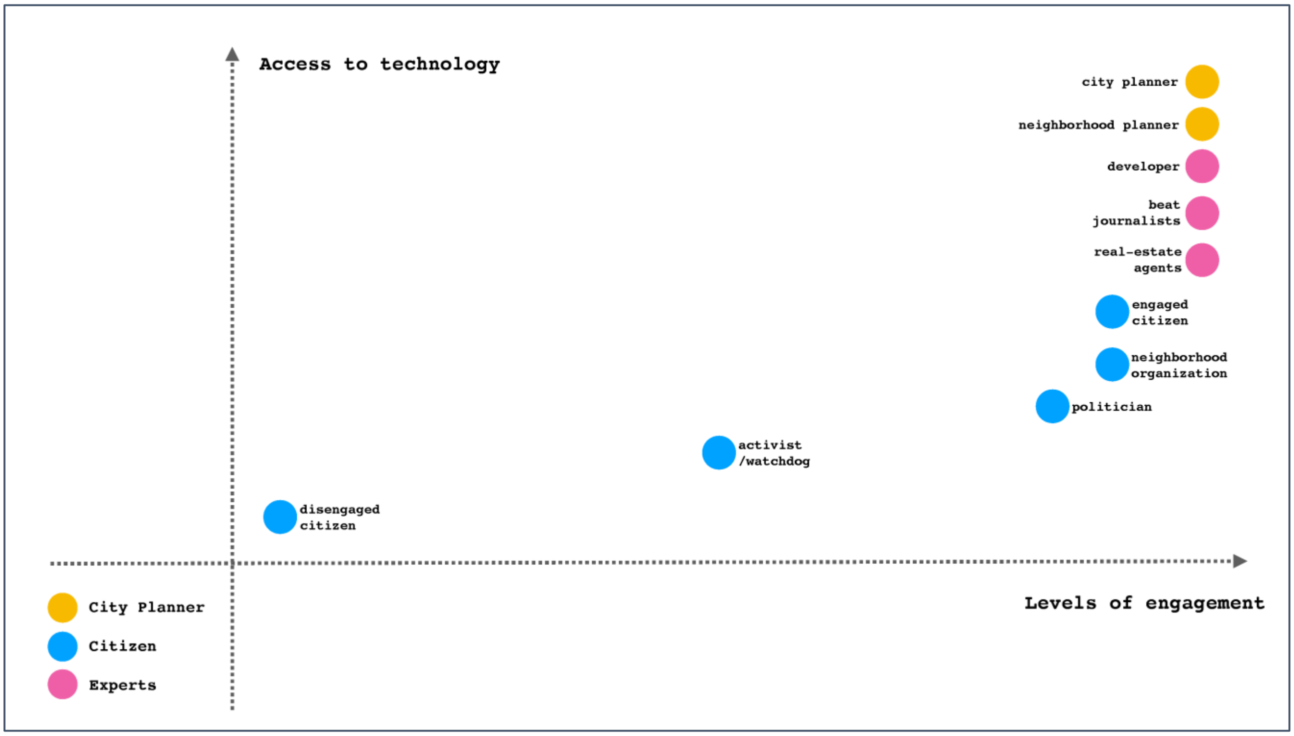


Figure 6.2 – Mapping of major user personae

For each of these personae, motivations, technologies and goals were also analyzed; a full set of these can be viewed at the link below.

https://drive.google.com/open?id=1w0XTSx3TkxoQWsZn0efFz6MYl4uyNo_w

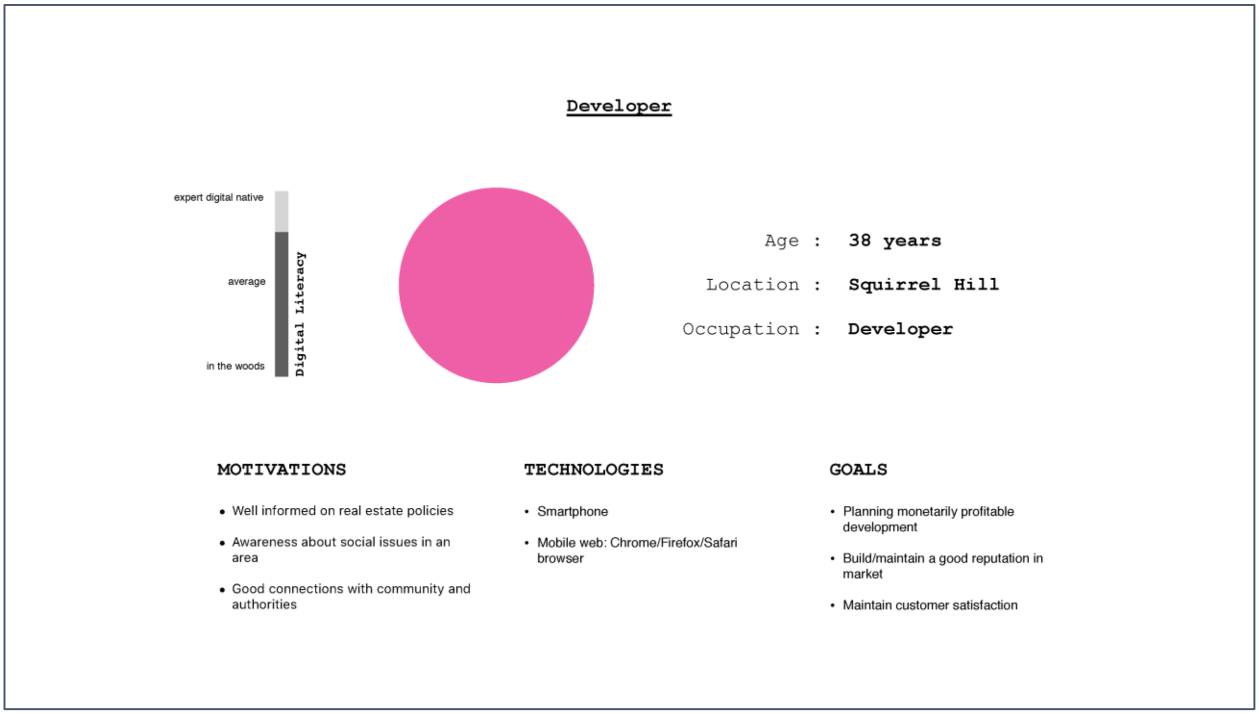


Figure 6.3 – Sample Persona, analyzing motivations, technologies, and goals

3. What do each set of stakeholders need to be able to do?

a. What are parameters for those interactions? (e.g., what interactions do different technologies afford: viewing vs. manipulation; manipulation of what factors such as road structure or building parameters such as number of stories?)

   This question was gradually resolved through the semester based on information from the project team.

4. What browser-based technologies are available and how will they integrate with 3D?

This question was ultimately resolved less on the basis of how technologies integrate with browsers and more with how the integration of technologies affected browser performance. Further, certain technologies were less viable due to either constraints on the "load" a technology could handle (such as limits on file size) or limits on end-user equipment (e.g., performance of a premium smartphone vs. a budget phone, or even native differences in platforms such as Mac, Windows, iOS or Android).

Later conversations with the full project team raised another question: How viable are these technologies from a workflow process for the constituents involved, including but not limited to developers, architects, city planners and others involved in the planning process?

Consumer Technology

What consumer-facing technologies are available for the visualization of 3D planning data?

At the time of the research, the current state of consumer technology, while promising, immediately limited the consideration of certain approaches for this project.

On May 02, 2018, Andrew Twigg delivered a presentation to the Civic Leadership Academy, a city program to “more informed, effective and inspired community and civic leadership by giving City residents an opportunity to learn about their local government.” [1] This presentation was an opportunity to share with citizens a kind of “state of the web” along with considerations for the project.

The crux of the presentation [2] focused on the fragmentation of devices used to access the Internet, with a particular focus on mobile technologies due to their pervasiveness. The takeaway points:

- There are a complex set of conditions affecting internet access, including socio-economic and infrastructure issues
- There is no across-the-board standard technology/technologies in citizens’ hands
- Device fragmentation and computing power varies greatly

This last point is especially true with respect to technologies such as AR and VR which require more recent equipment with greater computing power. While each of these technologies has their advantages, they also face challenges: AR allows representations to appear in their actual context, but it can be difficult to calibrate AR models to appear in the right location, and older devices aren’t powerful enough to do it. As point of reference, Google is only now (as of February 2019) beginning to test AR for navigation to select users on select phones, and this approach requires that data from the environment be available so the system can calibrate. [3]

VR has its own limitations: it still requires a capable smartphone, but it also usually requires viewing hardware which is not commonplace.

Other web technologies, which are very reliable, can show representation of 3D models:

- Images are easily accessible on the web.
- Video, while requiring more bandwidth/load time due to file sizes and more processor power to play, is broadly supported on common consumer technology.
- 3D rendering technology for the web has variable viability depending on the device accessing the rendering.

The ideal solution should be:

- **Feasible:** meaning that it can be built and maintained with relative ease.
- **Viable:** in that it is sustainable from an economic perspective as well as an adoption perspective.
- **Desirable:** in that people using the system will prefer to use the technology, although the idea of "prefer" is admittedly weak, so this is mostly considering that we are not introducing a solution that is unpleasant to use.

Choosing the Right Technologies

Ultimately, a limited set of technologies for 3D rendering were in consideration. From a workflow perspective, this scenario was devised as a way to consider what needed to take place in the process of moving a planning project from origination, through city planning, to citizens.

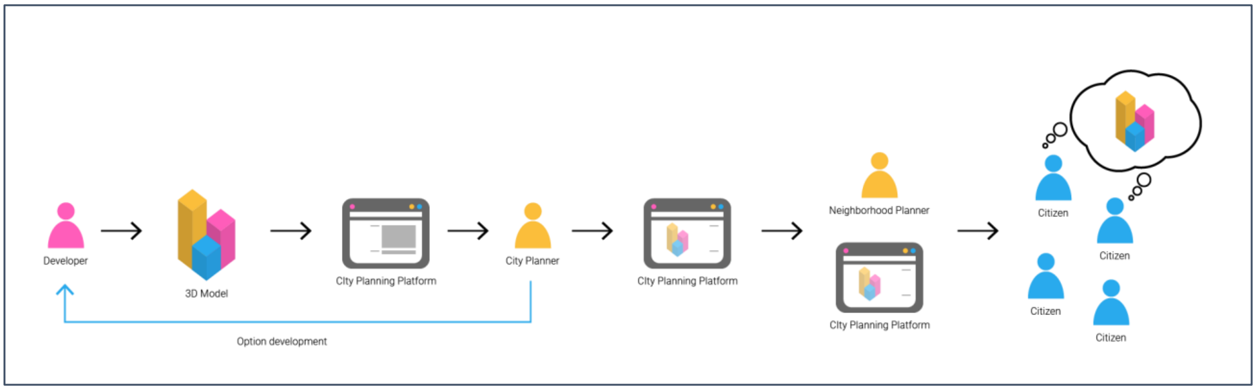


Figure 6.4 – City planning workflow with proposed City Planning platform

But recognizing that real-time 3D viewing of models would not work under all conditions for all users, a successful tool would also need to use other 3D representations. Additionally, the City of Pittsburgh already had an extensive form in place to gather complete project information in submission of projects for review by City Planning. So an ideal system would need to account for the input of not only a 3D model, but also images, video, and the information which is submitted during a review process.

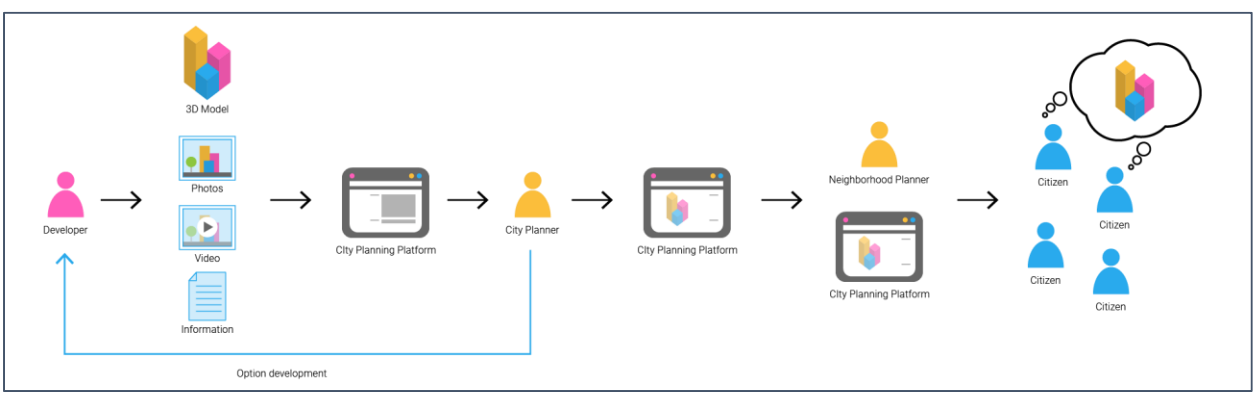


Figure 6.5 – City planning workflow with proposed platform, accounting for other types of data

Additional Considerations

A number of other factors affect the development of a tool for public communication in this context:

1. It should be inexpensive, to avoid adding significant costs to a city planning process.
2. It should be usable by people with varied technical skill levels; generally something that requires relatively common computer literacy skills is ideal. This means looking at technologies rooted to basic website conventions such as web forms, standard User Interface patterns, and paradigms such as word processing and office productivity tools.
3. It should support different use cases. In this context, for example, it would allow a developer to upload a project; a city planning employee to manage the project and collaborate with the developer to make sure the project meets city requirements; another city employee to share the information with community organizations and/or the public; and the ability of non-city employees/public to view and interact with projects.
4. It should be extensible, as the current state of technology does not make implementation of more advanced features like VR and AR viable but may do so in the future. A system should eventually be capable of storing and rendering that kind of data.
5. Last, but hardly least, it should integrate with other systems. Cities have varied technical infrastructures. In this case, the City of Pittsburgh City Planning Department has a software-based tool in development for digital management of city planning projects. So an ideal system will be able to take input and give output to other digital systems.

There are a number of platforms which could meet the requirements stated above. Consideration of open-source software rose to the top because the model being implemented as a proof of concept on this research study should easily be distributed to other city planning departments with minimal licensing issues.

Proposed Prototype Model

In the end the following solution was selected:

- **WordPress software as a Content Management System (CMS).** WordPress is open source, it is widely used (33% of the web runs on WordPress), it is flexible, and it is incredibly user-friendly out of the box. The interface for data input uses standard web form conventions and is relatively easy for developers to work with it.

  While there are other CMS platforms that are designed for cities, municipalities, and civic departments, it is our opinion that because these platforms are not open source, they can be costly to implement. They are services, which mean they have ongoing costs. While many of these platforms cover many different functions, the idea of integration of disparate technologies and utilization of code libraries like Three.js opens up a complex set of concerns. By contrast, WordPress has a long, proven record of being open and flexible. WordPress is also a familiar platform within the web development community, implying that it will be relatively easy for cities and planning departments to identify resources to assist with implementation, customization, and upkeep.

- **Advanced Custom Fields for extension of core WordPress functionality.** Advanced Custom Fields is one of the leading WordPress plugins. While it is a commercial product, it has over 1,000,000 installations [4], and the "Pro" license is $100 [5], a low price for the number of hours that might be spent in a custom configuration in support of a similar feature set. The plugin allows for the addition of custom fields to the back-end interface which can allow users to create input specific kinds of information. For example, one might be able to add fields for video or images of a project: fields to gather project information such as address, square footage, stories, the number of parking spaces, or other technical project information. Having this information available in explicit fields rather than entered in plain text form allows for each piece of information to be stored discretely in the database and retrieved depending on the context. With a developer's input, city planning employees could, for example, view all information and also edit irrelevant information to be displayed in a public-facing interface.

- **Three.js.** Three.js was chosen for the web-based display of 3D models for a number of reasons:
    - It is publicly available, open-source software, so it is available at no cost.
    - It utilizes WebGL, a broadly supported JavaScript API, which means broad browser support on desktop and mobile devices [6].
    - It supports a number of common 3D model formats, including Blender, openCTM, FBX, Max, MTL, and OBJ [7]. It also supports WebVR, an experimental web-based VR format [8], which indicates a potential future-state for the Three.js technology.
- **HTML, CSS, JavaScript.** While this is, perhaps, implicit in the selection of other technologies, the platform uses HTML, CSS, along with JavaScript to deliver the interface to all end-users. This means that the tool can be accessed in a browser and does not require the installation of any special apps.

Conclusion

While there are many emerging technologies such as VR and AR which have great potential to help citizens understand proposed changes in a city planning process, given current technology limitations—especially on the citizen side, it was considered that browser-based technologies afford the greatest opportunity to realize a viable tool for communication in the planning process.

The proposed prototype model integrates a combination of web technologies that utilize widely available standards—images, embedded video, PDF files, and HTML—along with more demanding technologies such as browser-based real-time 3D rendering using a standard, JavaScript-based technology (WebGL). While the latter of these (real-time 3D rendering) require more advanced hardware, even mobile technology such as phones and tablets are quickly becoming more capable of running these technologies and older devices incapable of rendering 3D models can access images, video, text, and other project documents. The use of WordPress as a means to manage the information in a flexible Content Management System make the proof of concept easy to develop, maintain and distribute.

Additionally, while the beginning of this research was oriented toward the technology used to communicate *to* the public, what emerged was a real need for a city planning process to more centrally manage the flow of information—perhaps in a streamlined platform—in a way that makes it easier to gather, manage, and share information between multiple parties (such as developers, city planners) with an end-goal of communicating that information to citizens. The proposed prototype model is based on widely available and/or open-source, inexpensive technologies: HTML, CSS, PHP, WordPress, MySQL, JavaScript. These technologies can be extended and updated with relatively minimal effort as end-user devices become more powerful.

References

[1] Civic Leadership Academy, http://pittsburghpa.gov/oca/cla

[2] https://docs.google.com/presentation/d/1AP8XPaIKjSHlqtveNI-6K0FgBSLcVBwf3OSgR-g2vZI/edit?usp=sharing

[3] https://www.wsj.com/articles/its-the-real-worldwith-google-maps-layered-on-top-11549807200

[4] https://wordpress.org/plugins/advanced-custom-fields/

[5] https://www.advancedcustomfields.com/pro/#pricing-table

[6] https://caniuse.com/#search=webgl

[7] https://threejs.org/docs/index.html

[8] https://en.wikipedia.org/wiki/WebVR

7. LITERATURE RESEARCH SUMMARY

In the 1950s, 60s, and 70s universities were at the root of early research and creation of 2D and 3D Computer Aided Design (CAD) applications. For example, researchers at Massachusetts Institute of Technology's Lincoln Laboratory, in collaboration with the US Air Force, developed the first major real-time, computer-based command and control system called SAGE (Semi-Automatic Ground Environment). Designed as a new air defense system to protect the United States from long-range bombers and other weapons, the SAGE system sent information from geographically dispersed radars over telephone lines and gathered it at a central location for processing by a newly designed, large-scale digital computer. MIT and Ivan Sutherland were also recognized for the creation of "Sketchpad, one of the first interactive CAD systems.

The Pittsburgh region academically contributed to the early development of algorithms for Computer Aided Design programs through work produced by Professor Charles Eastman at Carnegie Mellon in the 1970s. Eastman was the first to develop simple algorithms to display patterns of lines at first in two dimensions, and then in three dimensions.

Commercial CAD applications first appeared in the early 1980s. In 1982 powerful mini computers began to appear at (relatively) low costs. The affordability of hardware was a major step forward and by 1984 CAD technology was competitive with traditional methods of drawing. Later in the decade, basic 3D tools began to appear. Not only aircraft were designed using computers, now it was possible to economically design domestic products with complex 3D shapes using a computer. Eastman, then a professor in the Colleges of Design and Computer Science at Georgia Institute of Technology, and colleagues, developed the Building Description System (BDS), which is a library of several hundred thousand architectural elements, that can be assembled and drawn on screen into a complete design concept [1] and "Building Product Modeling" tools for practitioners that were later rebranded as Building Information Modeling (BIM). Although he retired from teaching in 2018, Eastman, widely known as the "Father of BIM", continues to work with the software industry in the areas of BIM, parametric modeling, and the integration of digital tools and workflows.

The early 1990s saw even lower hardware costs that allowed CAD applications to become commonplace in many architectural and engineering firms. Throughout the 1990s the sophistication of CAD programs continued to evolve. They began to "talk" to other applications via SQL (structured query language). Interfaces were established allowing links between CAD and databases. Advanced rendering and modeling applications also appeared in many architecture firms. In the mid-90s representation programs enabled CAD users to visualize their designs using rendering and animation packages to describe the shape and intensity of light energy distribution from a light source, natural light according to location, and orientation of objects. Designers and architects used such tools to study different architectural finishes and lighting in a realistic environment and could easily present a variety of solutions in client presentations. Architects could choose between producing still image renderings, applying motion in a model, both techniques presenting clients with a better understanding of size or depth. [2]

Figure 7.1 – Example of a rendering using Autodesk Viz

Photo source: The Design Alliance Architects, Pittsburgh Engineering Magazine, 2005

While 3D CAD, through the use of existing floor plans, elevations and sections, could generate a fully 3-dimensional electronic model in a matter of hours, a limitation was the ability to apply dynamic changes to a model. The limitation of instantaneous and dynamic changes to a 2D/3D model was solved with Building Information Modeling (BIM) that enables parametric technologies.

Commercial applications of BIM were seen in early software tools such as ArchiCAD (by Graphisoft) developed in 1982 in Budapest Hungary. Using similar technology to Eastman's Building Description System program, ArchiCAD became the first BIM software available for personal computers, focusing at first on residential and small commercial projects. In 1988 the Parametric Technology Corporation (PTC), founded in 1985, released the first version of Pro/Engineer, a mechanical CAD program that utilized a parametric modeling engine. Irwin Jungreis and Leonid Raiz left PTC and started a new company, Charles River Software in Cambridge, Massachusetts. The goal was to create a version of the software that could handle more complicated projects than ArchiCAD. By 2000, PTC had developed Revit. It was written in C++ code, utilizing a parametric change engine, made possible through object-oriented programming. In 2002, Autodesk purchased Charles River Software and promoted Revit in competition with its own object-based software "Architectural Desktop." [3] The percentage of companies using BIM jumped from 28% in 2007 to 71% in 2012 with the heaviest use by contractors, followed by architects and engineers. [4]


Figure 7.2 and Figure 7.3 – ArchiCAD example showing artistic and detailed renderings Source: University Library, Freiburg, Germany DEGELO ARCHITEKTEN, www.degelo.net, Photo Source: © Barbara Bühler

BIM applications today integrate visualization and analysis tools allowing users to create immersive 3D experiences. There is a more fluid design process and collaboration between architecture, engineering, construction, and facility management using cloud-based collaboration tools. [5] Architects and engineers use BIM to develop precise models that can detect conflicts, show structural weaknesses, and identify design quality problems. Integrating 2D and 3D in BIM models that provide accuracy and flexibility means less time spent in the design phase of a projects resulting in cost savings in design and construction. 3D "what-if" scenarios allow design professionals to communicate designs with clients and the general public to confirm designs or to participate in making changes. In addition to collaborations in the Architecture Engineering Construction (AEC) industry, BIM integration is making its way to Geographic Information Systems (GIS).

A driver for the integration of BIM/GIS integration is the accelerated population growth in urban areas. By 2050, the global population is estimated to reach almost 10 billion with approximately 70% living in urban areas. This growth and density leads to increases in energy use, water demands, and complex transportation needs. By integrating detailed BIM models with GIS information at the neighborhood, city, or regional scale, planners and urban designers can better understand how buildings and infrastructure will interact in the built environment. Detailed 3D BIM models that can include details such as energy use will promote and facilitate sustainable design and environmentally responsible planning and design practices. [6]

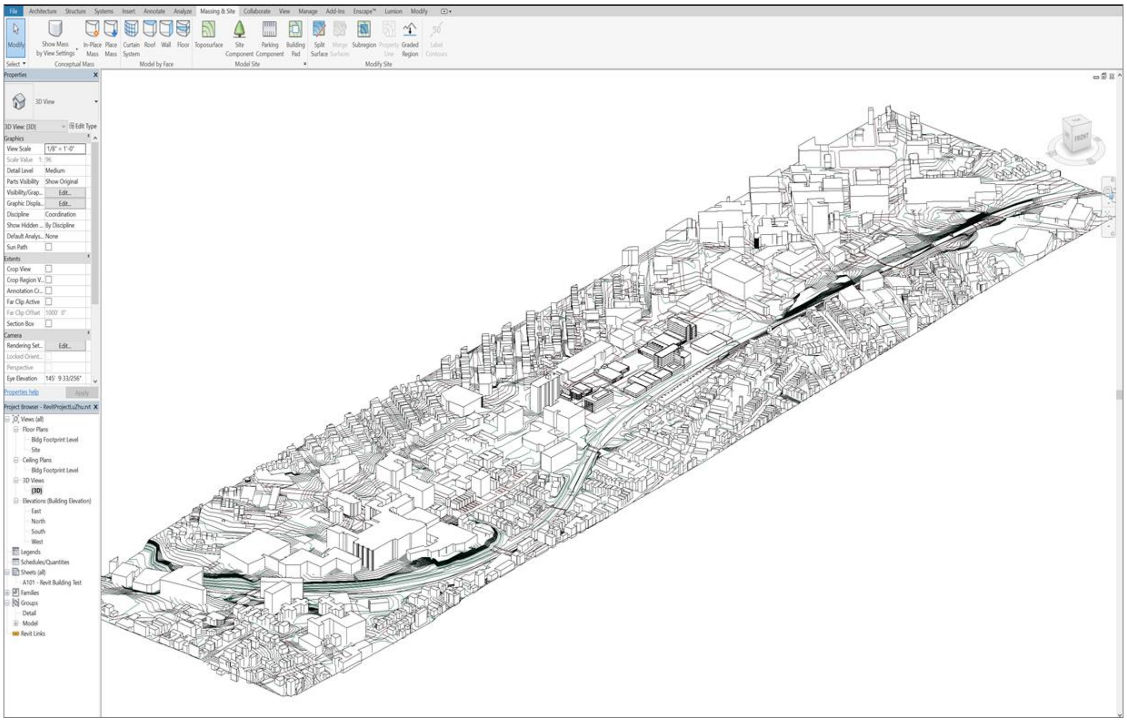


Figure 7.4 – Autodesk Revit model used for urban design scenario

Source: Lu Zhu, Master of Urban Design student, Carnegie Mellon University

While CAD and BIM are ubiquitous in architecture, engineering, and construction (and now urban design and planning), augmented and virtual reality has been a more recent integration. The history of virtual reality can be traced to 1838 with the use of stereoscopic photos and viewers. Charles Wheatstone's research demonstrated that the brain processes the two-dimensional images from each eye into a single object of three dimensions.

Figure 7.5 – Original stereoscopic images

Photo Source: Virtual Reality Society (VRS), UK

Viewing two images (or photos) through a stereoscope gives users a sense of depth and immersion and the design principles of the stereoscope are used today in low-budget VR head mounted displays for mobile phones such as Google Cardboard. [7]

Figure 7.6 – Google Cardboard device
Photo Source: Virtual Reality Society (VRS), UK

The first example of a VR head mounted display was seen in 1960 through Morton Heilig's invention of the "Telesphere Mask" that provided stereoscopic 3D wide vision with stereo sound. This was followed in 1968 by a head mounted display, invented by Ivan Sutherland and his student Bob Sproull, which was connected to a computer instead of a camera. The 1990s ushered in a series of VR glasses used in movies and the gaming world. Gaming companies such as Sega and Nintendo developed low cost portable 3D gaming consoles. Movies, such as *The Lawnmower Man* (1992) and *The Matrix* (1999), had major cultural impacts and brought to idea of simulated reality into mainstream conversations.

The use of virtual reality (VR) and augmented reality (AR) in recent years has expanded with the invention of light-weight smartphones and smart tablets with high-density displays and 3D graphics. VR headsets from companies such as Oculus Rift (purchased by Facebook in 2014) and similar headsets from Microsoft and Sony Computer Entertainment are indications that the consumer devices will continue to be designed and will become ubiquitous across many industries. [8] Software companies such as Autodesk and Esri have incorporated Augmented, Virtual, and Mixed Reality into their software such as 3ds Max, VRED, Forge, Maya, and

CityEngine. Applications for immersive design include conceptual design, design review, training and simulation, immersive storytelling, and remote systems control and analysis. [9] Using 3D GIS models that can be exported to applications such as Unreal Studio, planners can collaboratively review and compare multiple urban planning scenarios (using multiple VR headsets), interactively analyze sun shadows throughout the day, or virtually teleport and immerse themselves into a 3D city model and view current situations and future scenarios at full scale. [11]

3D models, renderings, animation, and AR/VR are now widely used in the architecture, engineering, planning, and design industries. It is important to understand the differences between 2D and 3D in order to determine whether 3D models should be used in a particular project. In qualitative field observations, Springmeyer et al. [11] noted that “2D views establish precise physical relationships, whereas 3D views provide a more qualitative method for presenting ideas to others”. Their studies demonstrated that for tasks such as orienting and positioning objects relative to one another, a 3D view helps gain an overall understanding of the space compared to a 2D view that provides precise details. For example, “a radiologist might use 2D scans to see details without occlusion whereas they might use 3D scans to gain an overall qualitative understanding of the scan and to explain procedures to patients or other physicians”. Similarly, CAD models can be viewed from standard 2D orthographic views (such as elevations and sections) and also used for precise editing and measurement and oblique viewpoints to assist in understanding of a 3D structure. [12]

Research by Dübel et al. [13] indicates that “the decision to use 2D vs. 3D data depends on various factors such as data complexity, display technology, the task at hand, or application context. An example might be the available screen space or number of items to display”. Their research states that “2D is more effective for precise measurement and interpretation and combining 2D and 3D generally increases confidence during problem solving. Technical aspects such as occlusion, clutter, distortion, and scalability are all important factors to consider when deciding between displaying data in two or three dimensions”.

Future trends in the use of 3D CAD, BIM, GIS, and VR indicate interoperable solutions and continued ease of use of technologies. See Section 10 for a discussion of interoperability and future 3D software needs for city planners and urban designers.

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8. SOFTWARE RESEARCH FOR CITY PLANNING

City planning and other governmental agencies involved with physical planning, development of the built environment, and the planning and documentation of physical infrastructure have universally adopted the 2D GIS platform for analysis and mapping and occasional 2D drawing tasks. Very little, if any, 3D software is in daily use. Few city planning departments are experimenting with or evaluating 3D software. Planning departments have typically been late and slow adopters of planning software mostly due to very limited IT budgets and lack of a strong demand for in-house initiation and execution of planning and design tasks. This is changing as new software tools are developed and adopted by private industry; planning departments are requiring more sophistication and performance of real estate developers and consultants; and civic engagement, public education, and public communication are now expected of planning departments.

Interviews with the Pittsburgh Department of City Planning and others revealed that some everyday tasks highly suitable for 3D technology were not possible, basically because of limited software budgets and not from lack of desirability. From these discussions, three city planning tasks were identified and desired for 3D software testing: 1) development proposal and zoning review; 2) preparing and facilitating local plans, zoning, and planning policy; and 3) public communications.

Development Proposals and Zoning Review

Site plans, schematic building designs, and variance requests are typically developed and submitted in electronic form using 2D digital drawings and renderings and sometimes in 3D format. These are good candidates for internal electronic analysis and evaluation, review by planning commissions or other authorities, and for public distribution and public hearing processes. When developers submit in formats compatible with a planning department's software, the review and permitting processes is most efficient.

Preparing and Facilitating Plans, Zoning, and Policy

3D software applications for decision-making and communicating with the public are good candidates for use by planning departments and for architects and others representing developers. BIM capabilities of software platforms facilitate addressing infrastructure and urban systems impacts of development proposals. By working from a common software and database platform, planning department and consultant staffs can share information real-time, provide instantaneous updates to internal databases, and prepare material for public communication.

Public Communication

Initial interviews and literature research in Phase I substantiated that 3D software is well suited for communicating with the public. Many citizens do not understand 2D plan drawings and elevation drawings, but can comprehend 3D depictions of physical proposals and zoning changes. Distribution of planning information over the Internet to mobile phones is an acceptable method of public engagement. Augmented reality visualization is gaining acceptance by the public. Virtual reality, however, due to its singular person viewing technology, is not a good medium for public communication, at least with the current technology.

Selection Criteria for Testing

Phase I provided the research team with a list of thirty-three 3D software programs used and cross-referenced them by type: CAD, BIM, GIS, Rendering, Animation, VR, and AR. There was a catch all category, termed “Other”, that included point cloud software, energy modeling, and gaming. As noted above, city planning departments favor GIS-based software. On the other hand, planning and urban design consultants and university academics and researchers use a wide variety of 3D software, including experimentation with new and beta-test software applications.

Phase II concentrated on gaming software for use with Vive VR. Unity was the primary VR software and SketchUp was used for building models, supplemented by Maya, Substance Designer, Illustrator, and Photoshop for detailed design items such as textures and objects.

Discussions with the Pittsburgh City Planning Department uncovered additional needs. Software capable of showing metrics will be needed as performance-based zoning and decision-making become more common. They also recognize that 3D software can provide a better visual and educational experience for a public that has higher expectations for more sophisticated and authentic civic engagement.

Based on the interviews with planning departments and the experience of the research team, the team selected software to be tested based on the following criteria:

- Common and readily available 3D software with proven and reliable track records capable of addressing the types of planning and design tasks identified by planners and urban designers: GIS, 3D BIM modeling, rendering, communications, and AR/VR.
- 3D software developed specifically for city planning tasks.
- Software capable of multiple tasks.

From these criteria, ten 3D software programs were selected for testing during Phase III. Each are described below with content provided by their respective developers.

Software Selected for Testing in Phase III

ArcGIS Pro

Esri, Inc.

ArcGIS Pro provides professional 2D and 3D mapping, high quality visuals, and advanced analytics. The software is integrated with ArcGIS Online, allowing users to easily create and share web scenes and other projects. ArcGIS Pro is well integrated with previous GIS software and handles large and small scale well.

For more information visit: http://www.esri.com/en/arcgis/products/arcgis-pro/overview

CityEngine

Esri, Inc.

CityEngine uses procedural modeling to allow those in planning, architecture, and design to build flexible scenarios within a large, realistic urban context. CityEngine has the ability to generate and texture 3D buildings, topography, and open space using 2D GIS data. For example, CityEngine can be used to create what-if-scenarios and easily visualize modification to zoning ordinances using Computer Generated Architecture (CGA) shape grammar rules.

For more information visit: http://www.esri.com/software/cityengine

Lumion

Act-3D

Lumion is a 3D rendering software that works with 3D models made in Revit, SketchUp, AutoCAD, and Rhino, among many other modeling programs. Lumion is used for detailed, realistic renderings. Lumion requires a high-quality graphics card.

For more information visit: https://Lumion.com/

Revit
Autodesk, Inc.

Revit Architecture is an architectural design and documentation software application for architects and construction professionals. Revit Architecture is specifically designed to support building information modeling (BIM) workflows.

For more information visit: https://knowledge.autodesk.com/support/revit-products

Rhinoceros (Rhino) / Rhinoceros 3D
Robert McNeel & Associates

Rhinoceros is a 3D application that produces precise representation of curves and free form surfaces as compared to polygon mesh-based applications. Rhinoceros is used in computer-aided design (CAD), computer-aided manufacturing (CAM), rapid prototyping, 3D printing, reverse engineering, industrial design, product design, graphic design, and multi-media.

For more information visit: https://www.rhino3d.com/support

SketchUp Pro
Trimble

SketchUp is a 3D modeling computer program for a wide range of applications, such as architectural, interior design, landscape architecture, civil and mechanical engineering, film and video game design.

For more information visit: https://help.sketchup.com/en/contact

Story Maps
Esri, Inc.

Story Maps is an online and cloud-based application that allows users to combine interactive maps with text, images, and multimedia content.

For more information visit: https://storymaps.arcgis.com/en/

3ds Max*

Autodesk, Inc.

3ds Max is a professional 3D computer graphics and rendering program for creating 3D animations, models, games and images. The software, built for Microsoft's Windows platform, is also capable of 3D modeling. (* Not tested)

For more information visit: https://knowledge.autodesk.com/support/3ds-max

Unity

Unity Technologies

Unity is a cross-platform game engine used primarily to develop video games and simulations for computers and mobile devices. It has been extended to work on twenty-seven different platforms. Unity is marketed as an all-purpose engine because it offers 2D and 3D graphics, drag and drop functionality, and scripting through its three custom languages.

For more information visit: https://unity3d.com/learn/support

Web Scenes*

Esri, Inc.

Web Scenes is part of the ArcGIS Online platform. Subscribers can upload 2D and 3D layers and share them online as 3D web scenes complete with a multi-scale base map. Creating a 3D Web Scene allows users to share scenarios in context with others, especially when combined with Story Maps. (* Not tested)

For more information visit: http://doc.arcgis.com/en/arcgis-online/get-started/get-started-with-scenes.htm

Additional Software Used

During the software testing phase, the MUD students used additional software programs to accomplish their project assignments and, later, the research team employed them and others to enhance the workflow and VR research as not all software is interoperable. These software programs were not evaluated.

AutoCAD 2017 for Mac	Autodesk, Inc.
ArcMap	Esri, Inc.
Excel	Microsoft
Illustrator	Adobe
InDesign	Adobe
Photoshop	Adobe
Unreal Engine	Epic Games
V-Ray	Chaos Group
Vuforia	PTC

9. RESEARCH FINDINGS

3D design and visualization is in the early adoptive stage and experimentation with new functionalities and formats will continue to evolve. 3D applications, and, in particular, augmented and virtual reality software, have improved significantly from when this research project began in fall 2017. Its path toward maturity is following the typical course of new software where experimentation is followed by industry acceptance. Eventually consolidation takes place with a few large surviving developers, followed by efforts to reach a wider audience with multiple specialized versions.

Users of 3D software will need software expertise, an understanding of file formats and their interoperability, and the ability to create code for formatting workarounds.

Gaming has been pushing VR/AR technology and has been instrumental in developing real-time 3D environments with appropriate levels of detail, speed, and peripheral devices. But it is a misnomer to categorize all VR/AR applications as gaming technology. Gaming and entertainment uses, however, have created a demand for more sophisticated hardware and software, increased capabilities, and lower costs. The large software developers of geospatial and 3D modeling are incorporating VR/AR within their platforms. City planners are now beginning to use AR for public communications where the ability to view proposed projects on portable devices by scanning over maps is an easy way for the public to view 3D.

The research in Phase I revealed that very few city planning departments currently use 3D software. While many departments have and depend on GIS software, they do not know how to use 3D software and lack guidelines and resources for its purchase. 3D requires expertise and is not intuitive for planners and urban designers. 3D technology is difficult to master and stand-alone applications are hard to use. Limited budgets of small and mid-sized city planning departments allow for only basic GIS software and a small GIS-trained staff. If and when 3D is needed, that service can be purchased on an as-needed basis. Bringing 3D into any planning departments will require dedicated funding, time, and effort.

The market for 3D software developed specifically for city planning departments and urban designers is not in high demand. Planning software will be a follower and late adopter of 3D software breakthroughs. Gaming technology, although enticing, is not appropriate for city planning as a design tool.

Adoption of 3D Software by Planning Departments

Since the completion of Phase III of this study, the Pittsburgh Department of City Planning (DCP) has begun to develop a dimensionally accurate 3D model for the entire city. The City also approved an additional GIS specialist in the 2019 budget that will allow more work on 3D modeling. In August 2018, DCP used two different augmented reality (AR) and virtual reality (VR) tools to receive feedback on a way-finding and signage project. A downloadable application allowed meeting attendees to view proposed signage to be placed around the city. This AR visualization of the signage provided a unique perspective on sign dimensions, visibility, and readability. The VR setup in combination with Google Earth VR allowed residents to explore large sections of Downtown and Oakland virtually and give feedback on optimal way finding signage locations.

3D Software as a Working Tool

Most city planning tasks are accomplished in 2D with a preference for displaying plan views, with constructed axonometric views substituting for 3D visualization. Axonometric views are useful but they are not realistic. Photoshop images inserted into 3D mapping context views, bird's-eye views, and perspective illustrations cannot fully depict the 3D qualities of the public realm.

Where 3D visualization excels is in view rotation and animation flythroughs of streets and public places. The stereoscopic nature of VR with headsets can put the viewer in the space or scene. 3D tools provide the planner and urban designer with the ability to simulate the real world, to better understand proposals and regulations in context, and to effectively communicate options with staff and the public.

When geospatial and 3D modeling exist in the same platform, 3D software allows for fast construction and reconfiguration of 3D massing models. For the planner who visualizes in 2-dimensional parcel plan views, this ability can widen the planner's tools for planning and design tasks. For the urban designer it can be a useful tool for creating and manipulating design of the public realm, especially when form-based and performance-based planning and zoning regulations are considered. Eye-level pedestrian views taken along a sidewalk or at an intersection are essential to conveying design intent and scale. 3D software can simulate and animate the eye-level view from the viewpoint of an adult, a child, a person in a wheelchair, a biker, or a vehicle operator.

Tools such as Stencil, Contour, and Traak from CMU spinoff company, Kaarta (www.kaarta.com) will allow planning departments and design firms to create inexpensive 3D high fidelity models in real time without the need of costly equipment or GPS coordinates.

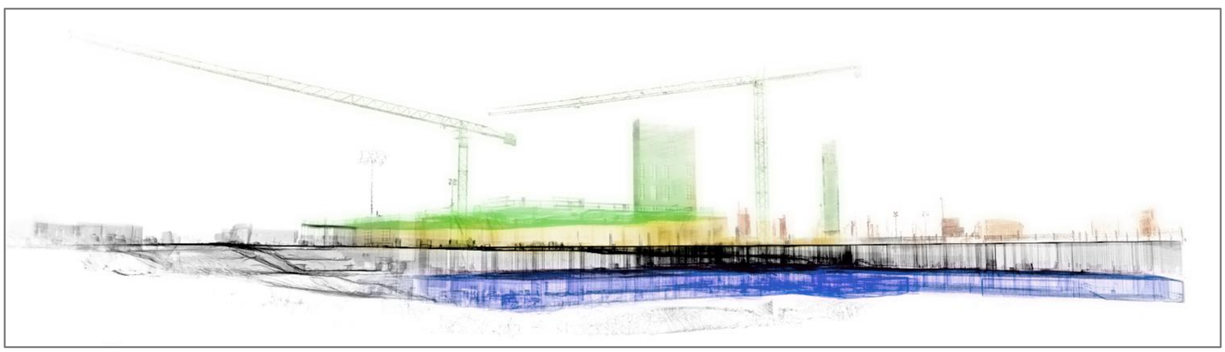


Figure 9.1 – Kaarta image of The Tepper Quad construction, a complex that encompasses 300,000 sq. ft. (27,000 sq. meters) at Carnegie Mellon University in Pittsburgh. Scanned with Stencil in less than 90 min. and merged in real-time on site

Reality depiction and other challenges remain. See Software Challenges later in this section for a description of observed differences between reality and 3D simulated views -- in particular how eye perception is different from 3D model visualization. Other challenges include adding surface features (textures) to facades and ground-level surfaces and depth of field, among others. As long as there is not an expectation of a fully-realistic depiction, 3D visualization software is a valuable design and communication tool.

3D Software as a Communications Tool

3D software is a good communicator of 2-dimensional mapping where volumetric massing creates three-dimensional views of otherwise flat surfaces. Three dimensional views are easily understood by those who cannot read plans or understand what is implied by conventional 2D mapping. 3D can imply realism better than other tools available to the planner and urban designer.

What may look good on an elevation view or a perspective rendering can be tested further and more definitively with 3D pedestrian eye-level, bird's eye, and multi-locational views of development proposals as a "proof of design."

Augmented reality is a reasonable lower cost substitute for 3D visualization of projects. AR can be a first-step to implementing three-dimensional visualization into the planning process or when budget restrictions do not allow for 3D modeling software. AR programs are available on mobile phones and tablets providing a cost-effective communications tool with the public.

Virtual reality, while useful for the planner and urban designer, is not public-friendly as an individual or group experience. For some, the "wow" factor of VR can be an unnerving and distracting experience for a novice user. VR is a single-person experience. The equipment (headset and control tether) is unwieldy for public meetings and simultaneous viewing on a large screen cannot convey the immersive experience to others.

Virtual Reality as a Design Tool

VR software was a new experience for all involved in the software testing. Testing was successful in capturing 3D environments that "felt" realistic for comparing urban design scenarios, but is less so in creating an experiential understanding of public space. VR is most successful when viewing tangible objects, such as buildings or physical features within a landscape, but less successful in depicting spatial qualities.

The student testers found VR to be useful for walk-throughs and making adjustments to the environment, such as moving trees to create a more dramatic setting or viewpoint. Because the student testers decided to model their urban design in 3D modeling platforms, they did not find

VR useful for modifying buildings and open space. (A geospatial modeling platform would have allowed for real-time design modifications.) The students noted that VR was helpful to identify where building heights and shapes should be changed, but not helpful with detailed site investigation due to a lack of program data libraries or the time to construct detailed content.

Figure 9.2 – Master of Urban Design students and faculty testing VR models

Real-Time Modifications*:* All the student testers at CMU desired and tried real-time modifications in 3D, but it proved cumbersome and time-consuming rather than creative and facile. They did, though, experience the effectiveness of VR when buildings were changed in size or location with each design iteration. The students and faculty at Jefferson University, who had more VR experience, made two observations. First, real-time modifications were useful for clients to visualize projects, but it was necessary for the software operators to have experience in both geospatial and 3D modeling software. Second, VR was not useful in a student design studio until two-thirds into a design project when the design is more defined, and, also, only when the user has had experience in both geospatial and 3D modeling software.

Realistic Depiction: For most of the student testers, VR had a "game-like" feel that was artificial and cold. While gaming software produces more realism than model simulation in VR, realistic content creation is a significant software challenge as realistic everyday landscape and infrastructure features are not easily available for populating a VR model. The research team also noted that when in a VR environment the viewer is more cognizant of buildings and objects than the space of the public realm. This is a problem when the objective is to design the public realm for the pedestrian experience and when soliciting public input. Lack of a realistic depth of field (see below) is a major hindrance.

Figure 9.3. – The difference between real world and VR visualization.

A CMU news story about the project can be found at the link below.
https://www.cmu.edu/news/stories/archives/2018/may/urban-future-tools.html

Scalar Depiction*:* Scale can be a challenge. The students found VR to be helpful at illustrating actual building heights viewed from a pedestrian's eye level, but the perception seemed skewed—not quite right. The buildings appeared higher than they imagined. Several students described the VR setting as a false scale.

Depth of Field: VR provides no depth of field. Line weights are treated equally whether in the foreground or the background. VR is currently not capable of human eye-perception relationships where the eye observes fine grain detail in the foreground, sees blurred detail in the mid-range, and loses most detail to monolithic or monochromatic shapes at far range.

Orientation: Viewer/operators using headsets cannot sense their own hands, arms, or feet causing uneasiness and disorientation. The student testers perceived their height in VR to be either higher or lower than actual. They concluded that eye level in VR is not the same as in real life and contributes to the non-realistic feel of VR.

Group Collaboration: Collaboration in VR is primarily a single-person experience. This is not an issue for individual designers. However, VR is not useful for team collaborative discussions, real-time design modifications, or public presentations unless everyone has headsets connected to the same VR experience, a technical and cost challenge for city planning departments.

Other Technical Challenges*:* Adding textures to surfaces and making changes in the 3D model were time-consuming and not easy or intuitive. Coding was necessary. Most students reverted to other measures, such as color-coding building uses, as a way around the problem. Modifications to buildings required exiting the VR program, changing the 3D model in its original application, and re-importing the model to the VR program. One student solved the problem by running the 3D modeling software simultaneously with the VR software, standing in front of the monitor, rising up the headset to make a change in the 3D model, then lowering the headset to view the result in VR. Another challenge was that co-planar surfaces with different surface materials caused an annoying flicker.

In addition to collaborative software, at the top of the student list for desirable 3D features was the ability to make real-time changes with all the software. This feature is currently only available with CityEngine and Unreal Engine because both software applications use the same geospatial platform. The students also wanted the VR experience to be more realistic, or at least as realistic as gaming software. Making VR a full immersion experience, like that experienced with more sophisticated gaming software, would better simulate environmental “realism.” Similar to the ETC students in Phase II, the MUD students found that realism of the VR and 3D environment increased by adding pedestrians on sidewalks, autos on streets, and the ETC students’ use of background sounds. After getting tangled several times with the wire tethers, there was a strong desire for wireless VR.

Software Challenges

3D Software is Complicated: 3D will be difficult for most planning departments. Staff members unfamiliar with 3D modeling software find that constructing 3D models, even when using a geospatial platform, is a complicated process. The student testers in Phase III, when faced with learning new software, usually chose the path of least resistance by using familiar software to complete design tasks. Learning new 3D software entails devoting significant time and commitment in the hope that the effort would be rewarded in the long run. The learning curve was faster for students experienced with 3D modeling programs.

The ETC students in Phase II, already familiar with VR software, spent much of their time understanding the language and design priorities of city planners and urban designers. For them the 3D software challenge was more about learning a foreign language (urban design methods and terminology) than adopting the software to solve design tasks. On the other hand, the students in Phase III, familiar with 3D modeling software and the language of urban design, were not experienced with VR software or personally equipped with the hardware functionality required of VR. In both cases, significant time was spent in the early part of each semester learning through trial and error.

Geospatial vs. 3D Modeling Platforms: 3D software has developed as two separate technologies that utilize different reference points and, consequently, different software platforms: one is location-based (geospatial/GIS) and the other spatial-specific (3D model based). Location-specific software utilizes geographic coordinates (latitude, longitude, and elevation) to place a reference data point at a specific geographic location. Spatial-specific software (Revit, Rhino, and SketchUp) use Cartesian coordinates to locate reference data points at the intersection of three axes (0,0,0) in a “space” void of geographic location. While the two technologies share many attributes and one can be transformed to the other, they operate differently. City planners typically use location-specific 2D geospatial (GIS) software, not 3D spatial-specific model based software.

In order to use both technologies buildings and objects constructed in 3D modeling software must be reconciled with the GIS platform to be useful for day-to-day city planning tasks. This is not an intuitive process. It is difficult to place model-based projects into a GIS system because the spatial 0,0,0 reference must be perfectly aligned with a specific latitude, longitude, and elevation point for compatibility. Once achieved, however, the building models remain as static objects within the GIS environment because 3D model software cannot be manipulated (reconfigured) by the GIS platform. To make physical design changes and show different building massing options, the GIS user must first export the building or massing model back to the 3D modeling software for changes, and then import it back into the GIS platform. This back-and-forth process is tedious. If 3D models come from several sources, the task may become unworkable and planners/urban designers revert to studying alternatives by hand drawing or not at all. This is similar to the problems faced by the students in Phase III trying to use VR software, where making design changes required returning to the 3D modeling software and then back to the VR platform.

Realistic Simulation: 3D software can somewhat simulate a "real" condition for design analysis and is preferable for public visualization over two-dimensional maps and traditional urban design drawings. However, 3D software, and VR in particular, do not provide true and realistic depictions because of equipment and software limitations inherent in 3D software. The challenges detailed in the above "Virtual Reality as a Tool" section exist in all 3D software whether geospatial- or model-based. Perceptual qualities, such as scale, depth of field, and body orientation among others are technical qualities will have to be improved in future 3D programs. They will remain "cartoonish" until the software can produce photographically realistic simulations. Camera techniques developed by the motion picture and gaming industries portend advancement in realistic 3D software development.

Compound Tasks: Modeling software is constructed to work on one building model at a time. City planners and urban designers, however, often work simultaneously with multiple buildings. When each building is a separate object, as is the case with 3D modeling software, making changes for multiple buildings is time consuming. Planners and urban designers need software programs that can modify both single and multiple objects. This limitation holds true for building facades. Creating realistic street scenes or block-long facades is a tedious process when working back and forth in separate object files.

Interoperability: Students in Phase III found that most 3D software was not collaborative with other 3D software unless developed by the same company. The test software did not allow real-time team collaboration for design and other planning tasks. The students were working with unfamiliar software within a limited time period and, as a result, became frustrated when found they could not work in a real-time and collaborative manner. The software did not have sharing capabilities with respect to four aspects: 1) not all software was compatible with other software; 2) FME transitional software did not solve all the bridging issues; 3) two persons could not work collaboratively within any of the geospatial or 3D modeling software; and 4) collaboration was not possible within virtual reality software or between VR and most 3D modeling software. Design tasks in 3D software are currently a single-person experience.

Software Compatibility: Although most modeling software theoretically can be converted to other file formats, the student testing found many instances where compatibility was an issue requiring workarounds to complete design tasks. It takes a sophisticated and experienced user to manipulate between formats and programs. For most everyday city planning tasks this is not necessary, but, when planners want to use 3D software, compatibility with other software is a significant challenge.

Need for Coding Expertise: Coding is necessary to modify specific aspects of most 3D software or to change formatting. An operator experienced in both software and coding is required, an expertise not often found in planning departments.

Purchasing 3D Software: The high cost of software purchase, training, and staffing is an issue for planning departments. Unlike professional consulting and service firms, governmental agencies do not provide planning and urban design professional services for a fee. Thus, they have limited ability to generate a funding stream for the purchase and maintenance of 3D software. Until local governments recognize and value the effectiveness and efficiency of 3D software with its broader economic and social benefits, planning departments will continue to be underfunded to purchase, train, and maintain 3D applications.

10. SOFTWARE INTEROPERABILITY AND WORKFLOWS

It is unlikely that a single piece of software will provide a universal solution to 3D visualization and analysis of development scenarios and zoning changes. Professionals use a variety of software applications based on the task at hand, but they tend to use familiar software rather than experimenting with new applications. Output and productivity are thus enabled or restricted by software choices. The workflow diagrams illustrated in this section organize connections between the off-the-shelf software tested in Phase III. They also provide a guide for an individual to perform basic 3D functionality tasks or to delegate particular or more-advanced tasks to qualified team members.

The software workflow diagram is in four specific performance categories:

1. Geospatial (location-based)
2. 3D Modeling and Visualization (spatial or model-based)
3. Virtual Reality (VR) and Augmented Reality (AR)
4. Communication

The categories and workflows are based on the feedback from the interviews with governmental, consultant, and academic practitioners on how they use the software. For instance, ArcGIS Pro and CityEngine perform tasks based primarily on a geospatial coordinate system and have been so categorized. Revit, Rhino, and SketchUp, used primarily for 3D modeling using the Cartesian coordinate system, are separately categorized as 3D Modeling and Visualization. They offer functionality that enables the user to visualize minute details as compared to geospatial software that has its strength in urban scale data visualization. The Virtual and Augmented Reality category is comprised of software that enhances the immersive experience of data visualization. Unity and Unreal Engine are essential for in creating 3D animation and VR and AR content. Although the VR/AR software is generally geared towards communicating an idea to prospective audiences, it is not solely intended for communication. The Communication category includes software that professionals and universities use for group presentations, printed material, and sharing information online.

The illustrations identify the most efficient workflow to perform tasks with the selected software but also offer software alternatives depending on the user's expertise. For example, to visualize an urban corridor with proposed changes, a user, based on familiarity or unfamiliarity with particular programs, can choose to develop and/or disseminate information via any of the four performance categories as the starting point.

Data interoperability between software programs is an integral part of the diagrams. A data format read by some software might not be compatible with the others. The workflow diagram highlights the data types that a user could use to manipulate data using different software programs. For example, a user will be able to map out the path to presenting zoning ordinances to the general public for review or to better engage the public using a range of Geospatial to VR/AR software programs. A model submitted to a city planning department by a developer can be viewed in a virtual context by planners as well as used to maintain a repository of proposed, existing, and under-construction changes. Conversely, city planning departments can provide and share data or information in formats compatible with programs commonly used by professionals, educational institutions, and research institutions.

A user can also trace back and forth the steps necessary to achieve a desired outcome with familiar software. For example, how does a user create a Story Map and present a VR demonstration of the same content? The workflow diagrams map/track the overlapping software programs and illustrate how to: manage interoperability; eliminate errors; and create stable output.

Workflow Overview of Tested Software

After the Phase III work was completed, the research team identified interoperability gaps, such as the need for VRML formatting, when attempting to link all four categories in a seamless workflow. VRML is a graphics file format based on the Virtual Reality Modeling Language (VRML). VRML files are primarily used for 3-D information on web pages. These files contain information about the graphics of the site, such as sounds, animations, lighting, and objects. In 1995, VRML became the first web based 3D format. VRML was unique because it supported 3D geometry, animation, and scripting. In 1997, VRML was ISO (family of quality management systems standards) and continued to attract a large following of artists and engineers. VRML is the most widely supported 3D format for tools and viewers, and it is a direct subset of X3d (where X stands for Extensibility). [1]

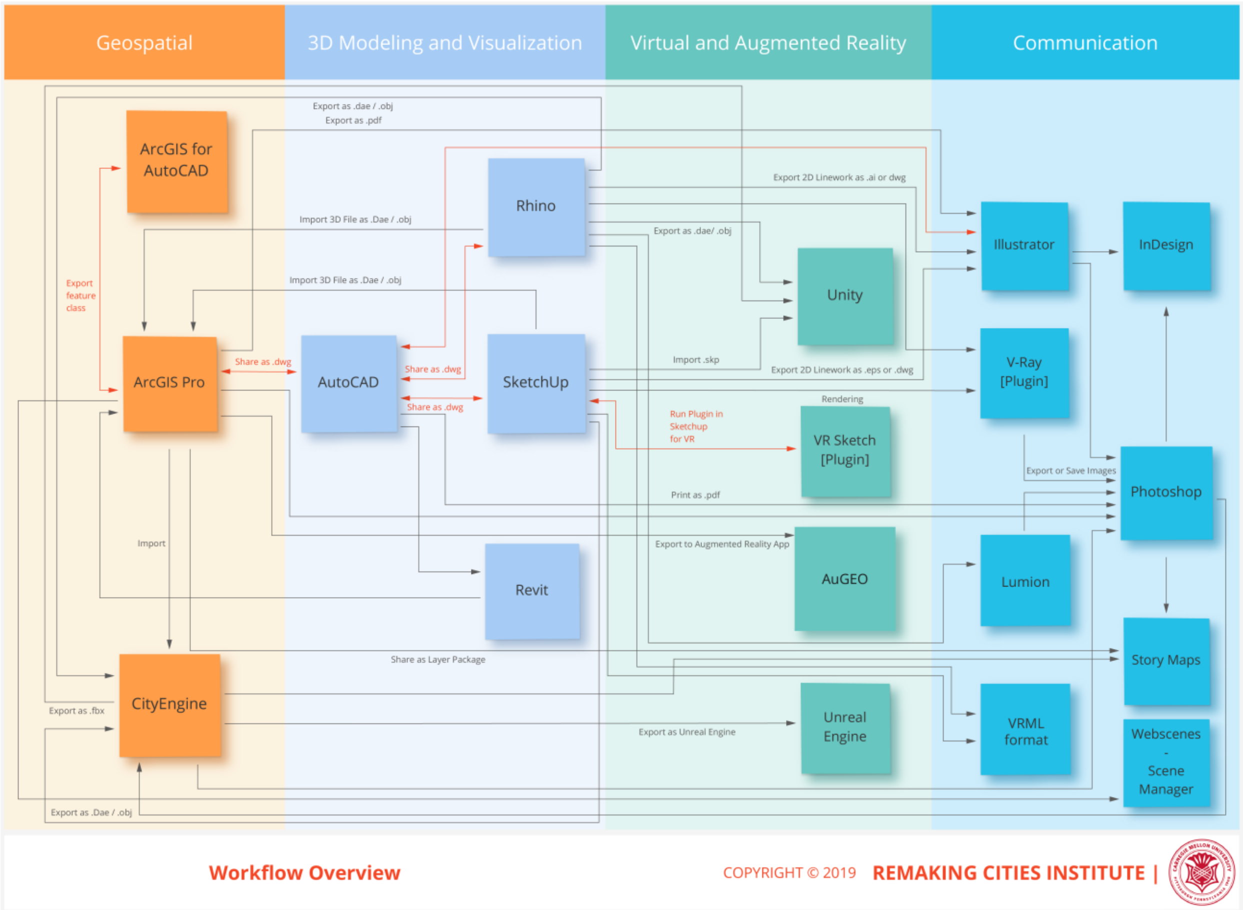
The Overview Workflow diagram is the tested software, including recent software upgrades with expanded functionality and additional software needed for linkage to complete a particular workflow path. For example, VR Sketch was added to SketchUp as a virtual reality plugin to expand its versatility. Similarly, Unreal Engine was added because it offers a template to visualize CityEngine scenarios in VR. Untested software added for increased functionality and linkages include the following: ArcGIS for AutoCAD (Esri, Inc.), VR Sketch (SketchUp Extension Warehouse), AuGEO (Esri, Inc.), Unreal Engine (Epic Games), and V-Ray (Chaos Group).

The connections between applications in red signal that they could use the same file format for data manipulation. Such interoperability allows users to benefit from the features provided by either application or a chain of software. The darker grey connections signal a one directional flow of data where files were saved to a different file format or a data file-type was not directly supported by the preceding application in the workflow.

High-resolution images for each workflow can be downloaded from the link below.

https://cmu.box.com/s/dutt54ohqjo5phhxad0udqpicogglk0j

Overview Workflow

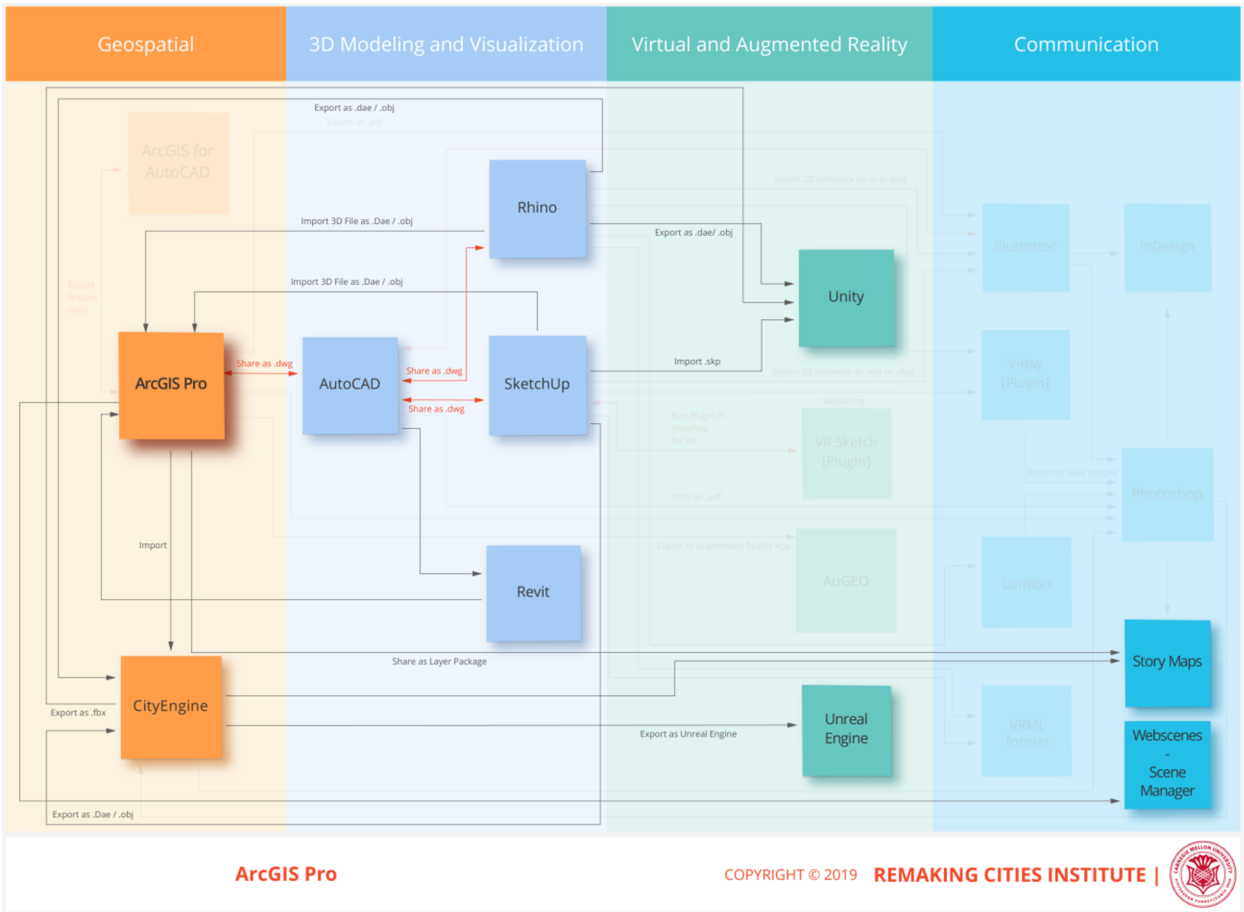


Common Workflow Pathways

The following diagrams show the workflow of five software programs commonly used in the Geospatial and 3D Modeling and Visualization categories: ArcGIS Pro, AutoCAD, Rhino, SketchUp Pro, and Revit. There is one workflow diagram per software, illustrating the workflow pathway for a specific task. Note: Each task is an example of the testing conducted as part of this research and is not inclusive of each software's total capability.

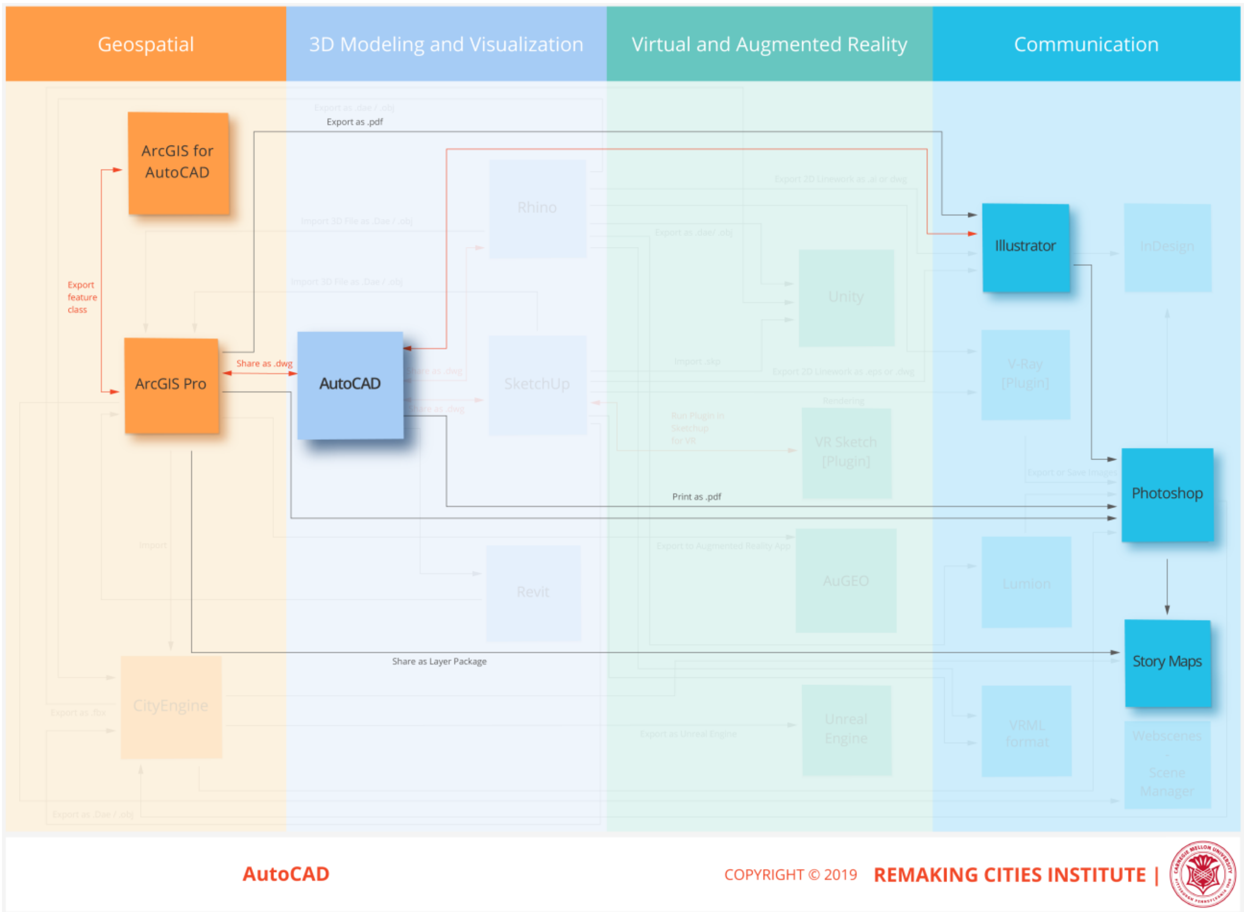
ArcGIS Pro – Task Example

Visualize different development options and publish online for discussion



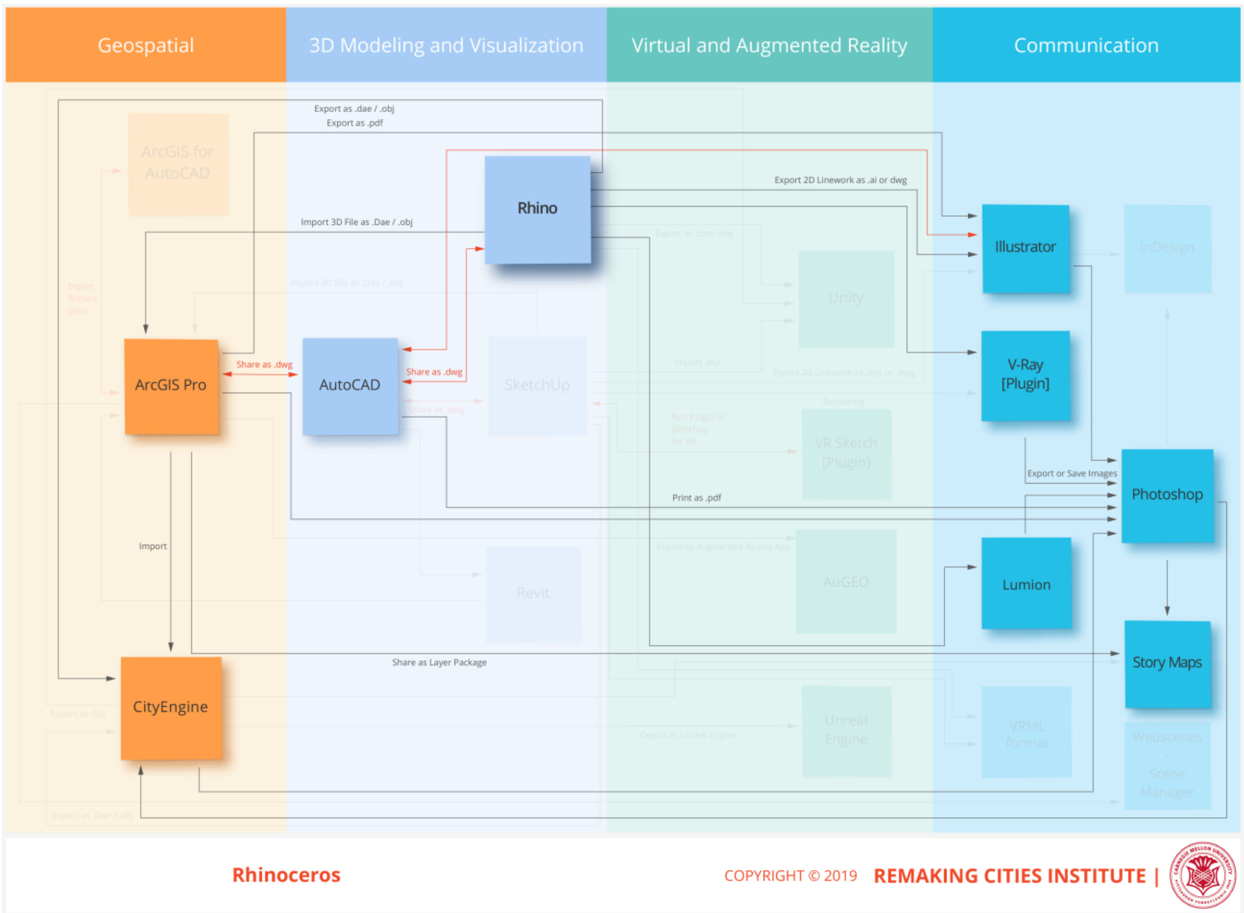
AutoCAD – Task Example

Prepare proposed zoning maps and disseminate through Story Maps



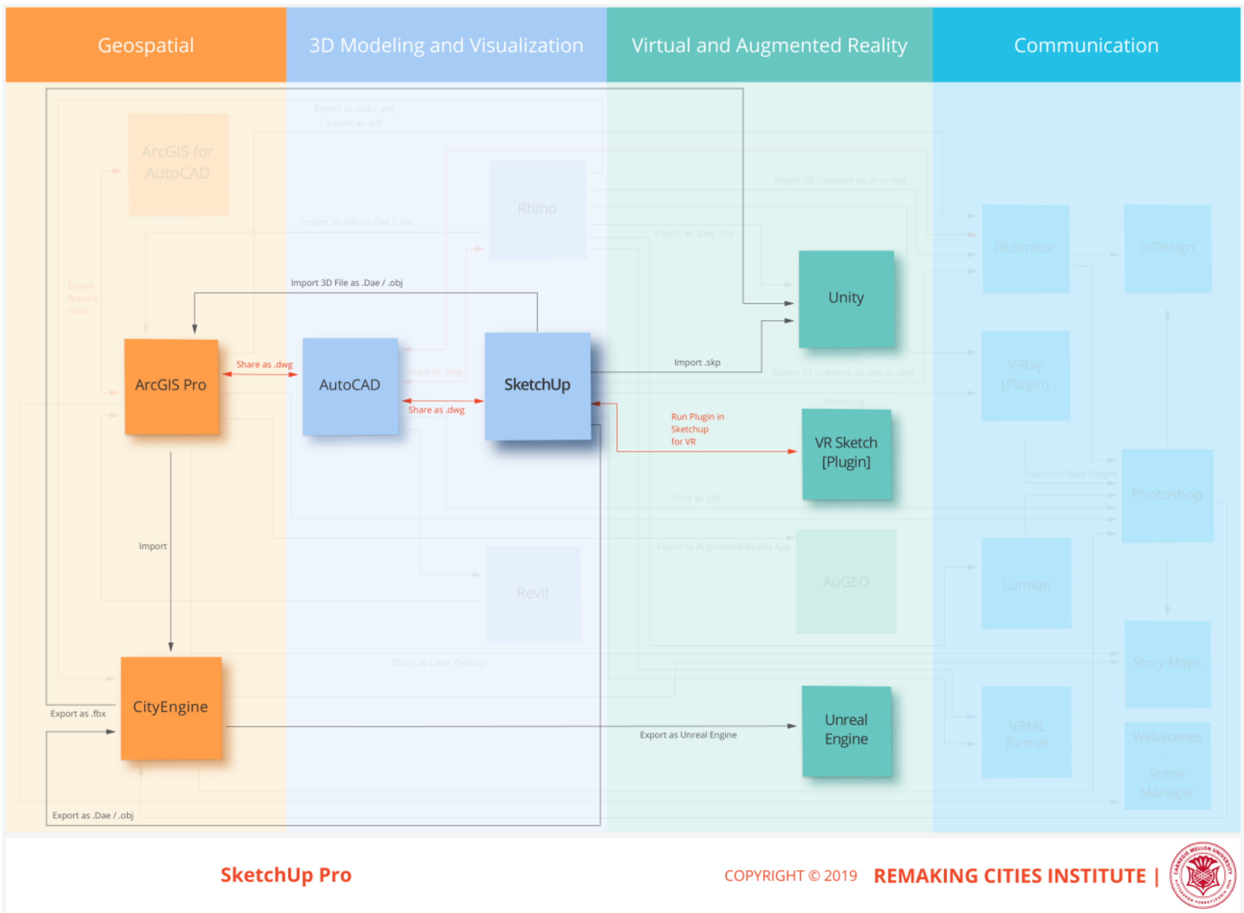
Rhino – Task Example

Publish Rhino models as Story Maps (public information dissemination)



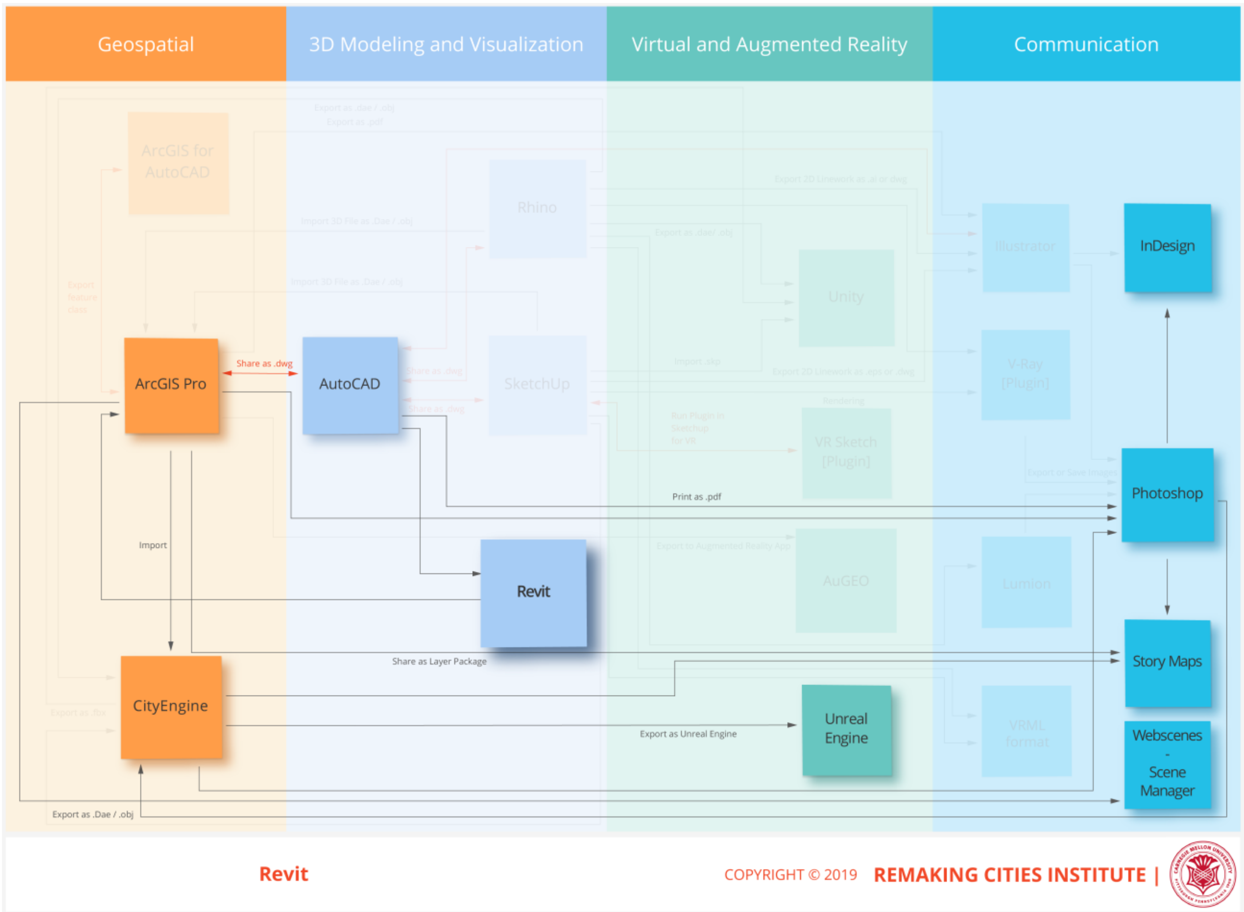
SketchUp Pro – Task Example

Sketchup to VR, preferably for design evaluation



Revit – Task Overview

View options for proposed developments in an urban context



Data Translators

One of the roadblocks to achieving a seamless transition between software programs and data manipulation/translation is the conversion of data from one platform to another. The conversion determines what type of data will be shared and converted. The user must be aware of the data required to perform different tasks in different software programs.

Interoperability in extracting or converting data is not a new idea, nor has it always been successful. Most software programs, present and past, have interoperability built into their system. Unfortunately, some of the most commonly used programs are not compatible with each other. In those cases, software such as FME by Safe Software, can play a critical role. Data translators can convert data from one platform to hundreds of others. For example, most users who still have early versions of ArcMap find it hard to integrate Revit (BIM) with GIS data.

FME Workbench converts BIM files to shapefiles and file geodatabases for importing to GIS software. The latest version of ArcGIS Pro corrects that problem and can now read native Revit files.

The ArcMap/Revit conversion example above insures that attributes in the BIM model will be accurately converted and retained in the GIS environment. Oftentimes, when data is transformed to a different category, loss of attributes can occur. For example, a GIS map containing the footprints of buildings when exported to a CAD environment may result in just the basic polygons being shown but with no other data than the area of the polygon. Data translators help retain some, if not all, of the data sets within both the CAD and GIS platforms. Conversely, attributes can also be assigned to elements that previously had none. The use of this capability/conversion can range from maintaining a 3D record of a city to querying spaces in a building for facilities management, and so on. A user can share their designs as 3D PDFs or as viewable online content best suited to the intended audience.

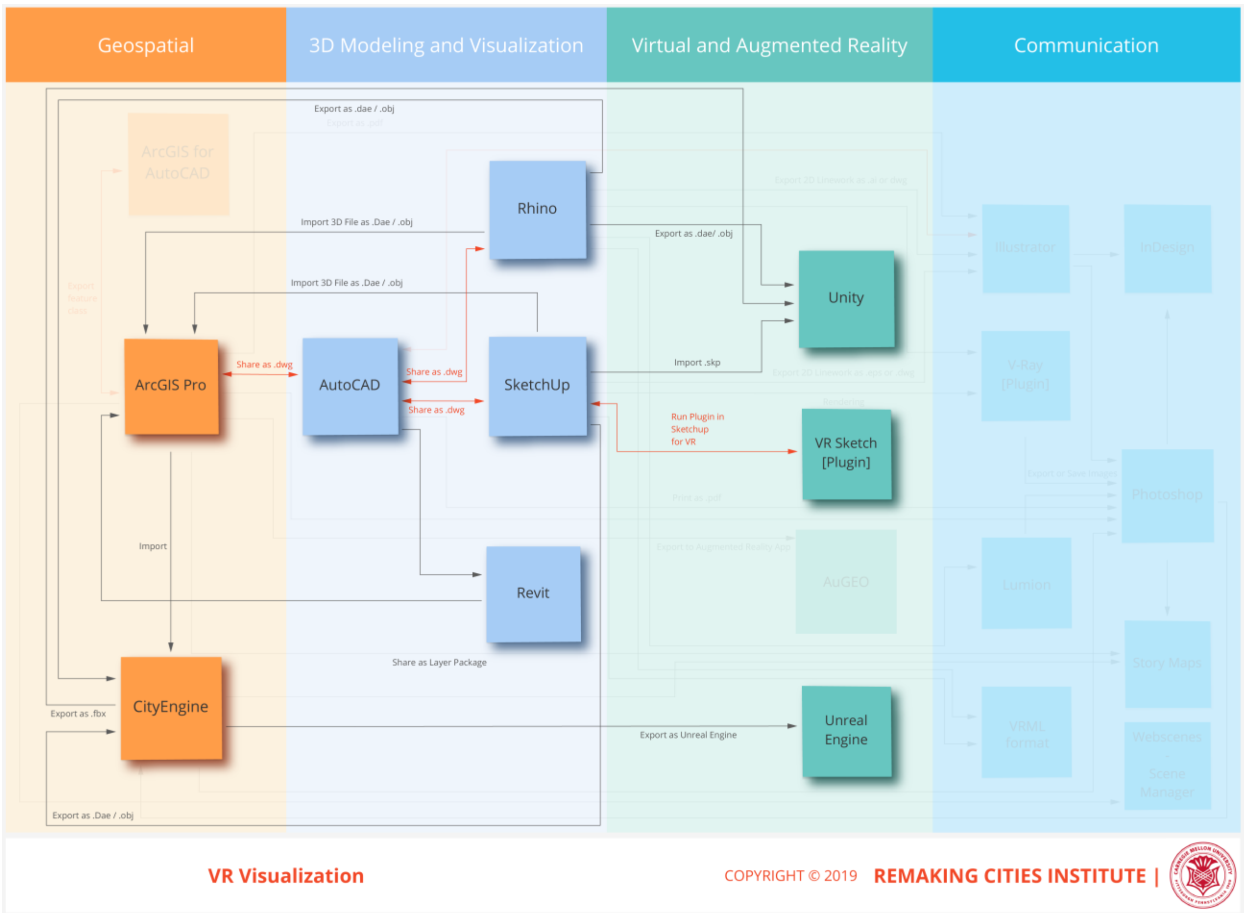
FME or data translators convert the data from one format to another. They do not have analysis tools built into them.

Viewing Multiple 3D Models in Virtual Reality

An important issue uncovered in the Phase III research was the inability of real-time design collaboration in virtual reality. While users can share VR headsets to view the same content, making real-time design modifications was only possible by using CityEngine, but not Rhino, Revit, or other software not using a geospatial platform. The testing also found that it was not possible to view design options for comparative purposes, such as determining if one public space design provided a more desirable experience than another when design elements were relocated within the option. The research team concluded that using CityEngine with Unreal Engine provided the best workflow solution for comparing design scenarios.

VR Workflow Using CityEngine and Unreal Engine – Task Example

Visualize different VR development options: ArcGIS Pro > CityEngine > Unreal Engine



By utilizing CityEngine's 3D modeling attributes within ArcGIS Pro's geospatial platform, their linkage with Unreal Engine's VR capabilities offers several advantages:

Showing Context in Unreal: The software provides the ability to navigate, rotate, and change model scales within the overall model context.

Moving Around Models: Ability to view at street level and teleport to any location within the model and the ability to move the view 360° to an unfixed teleport location is an important feature. Users can also readjust the scale for viewing in true size (1:1 scale). Sun lighting conditions are an automatic default of the Unreal Engine so there will always be shadows in the rendering.

Viewing Options Through the Controller: The software allows access options via the trackpad on the controller. It can also allow for simultaneous communication in real-time for referencing between different design scenarios.

Other Default Options: Changing the table height and the model size are possible.

The team was unable to delete the conference room view setting in CityEngine, which is helpful for orientation when first opening the software but undesirable as a permanent setting for all VR views.

References

[1] https://whatis.techtarget.com/fileformat/VRML-A-Virtual-Reality-Modeling-Language-file

11. RECOMMENDATIONS AND FUTURE NEEDS

Phase I research determined that few city planning departments use or are experimenting with 3D software. Some planning, urban design, and landscape architecture consulting firms have begun to adopt and integrate 3D visualization software into their daily work, but not yet in a major way. Some of the most important applied research is being done in university urban design programs.

Phase II and Phase III research concluded that 3D visualization was useful not only for in-office planning tasks for public agencies and private firms, but also for communicating with the public and clients.

3D software development is proceeding faster than the city planning profession can adapt and absorb. It remains complex and dependent on tech-savvy staff or the retention of costly outside consultants for 3D visualization services.

Below are overall recommendations for: 1) city planning departments; 2) software developers; and 3) universities. The report concludes with future needs and expectations for 3D software development.

City Planning Departments

Until 3D software becomes easier to use and more widespread in its city planning market penetration, these recommendations for city planning departments are intended to facilitate an initial exposure and use of this new software. Their adoption and use requires initiation by planning departments, not software developers.

Embrace Relationships with Local Universities: Universities make good partners with both benefiting in the exchange. For planning departments, universities provide planning research, interdisciplinary expertise not normally available, and opportunities to use student projects for exploration of actual city planning projects. For universities there are numerous possibilities available for engagement with the city: participation by city planners in classroom seminars and review of student projects; co-op or work-study experience for students; placement of students in permanent jobs; and partnering with the city on research projects.

City Planning Fellow Programs in Partnership with Accredited Universities: Universities can prepare graduates with 3D software skills to enter city planning departments as supported fellows to assist the department with 3D software training and adoption. Fellowships, funded by philanthropic foundations, software manufacturers, and professional firms, are both bridge career positions for new professionals and talent enhancements for planning departments.

New Hires: New hires with 3D software capabilities can be valuable assets for integrating 3D visualization even where 3D software has not yet been adopted. Their technical expertise can introduce 3D visualization methodology into the department as the need for that 3D software emerges and funding becomes available.

Volunteer for Beta Testing: Software developers are open to working with city planning departments for real-world testing of new software. This is a two-way partnership with benefits for both parties. Software developers will train staff in the use and intricacies of the new software in return for critical feedback. This may be time consuming for the involved members of staff, but the training and hands-on experience will allow all staff to be current with software trends.

Begin to Use 3D for Online Communications: Upload 3D designs of projects scheduled for public hearings in advance of the official meeting. Provide updates of ongoing planning initiatives in 3D when possible.

Require Online Submissions: Require that all projects seeking planning approval be submitted in 3D imagery formatted for direct exporting to the city website. One of the most frequently heard public requests is for timely and relevant communication of items scheduled for public hearing. Most people do not attend meetings in person, but they do have access to the Internet.

An important item often missing from most project submissions is an accurate illustration of street views of a project as viewed by pedestrians. 3D software has the ability to construct street views so that all parties can judge the “quality of place” of a proposed project.

Software Developers

Software developers should work closely with city planning departments to develop and test 3D software. The goal would be to expand its usefulness beyond visualization and to integrate public impact and performance measures similar to energy performance measures required in building design. Scenario planning is an application of 3D software that should be explored with planning departments, perhaps even involving gaming software. This would be valuable for in-house tasks as well as for public engagement.

City planners, urban designers, and landscape architects require geospatial and 3D modeling software to perform their professional tasks. Today, only the geospatial platform has developed 3D modeling software with the potential for real-time modeling within a 3D simulation. Just as the move to CAD software revolutionized the architectural profession, 3D and VR/AR software will revolutionize the planning and urban design professions.

Universities

City planning and urban design programs within universities are beginning to adopt 3D software as integral to their academic and research programs. Teaching 3D modeling software is included in most undergraduate and graduate curriculums in the US and geospatial software is beginning to make inroads. 3D software expertise should be expected of graduates entering the city planning and urban design professions. The MetroLab Network, a national grouping of over forty regional partnerships between cities and universities, provides an opportunity for sharing research and "lessons learned" for deployment of 3D technologies in city planning departments and universities.

Future Needs

The CMU research faculty foresees that 3D software will improve with its ability to document context and with expanded and higher quality libraries of realistic objects and textures for importing into design models. VR and real-time graphics are forecasted to be the next "new wave" with the ability of inserting models of buildings and public spaces into "real" contexts. This is now happening in gaming, the leader in these software advances.

For city planning tasks, the geospatial platform currently offers the greatest potential for both geospatial and 3D modeling compatibility. The GIS platform is capable of real-time design and model modifications when the 3D model is created within the GIS platform, an integration that is currently not available with 3D modeling software. Anticipated geospatial software development will focus on tasks specifically developed for the city planning and urban design professions and in university curriculums and research. Currently only one software developer, Esri, is leading this development, but the expectation is that other software developers will enter the field as plugin and platform creators. Seamless integration of BIM models into the GIS platform will allow architects and real estate developers to share realistic models of buildings and projects with city planners. And, integrating lidar technology will facilitate rapid generation of 3D models.

The research team identified enhanced software features that would be valued by city planners and urban designers:

Realism: The challenge is to increase the realistic content without requiring a high level of user expertise. City planning tasks primarily focus on parcels and parcel development, but there is an increasing demand for 3D modeling to analyze and communicate impacts on the public realm and to communicate these with the public. The more realistic, the better understood.

Eyesight Perception: Mimicking human eyesight properties with optional software settings for line weights (near and far) would produce more a more realistic depth of field.

Real-Time Design Changes in Virtual Reality: The time-intensive back-and-forth process between 3D modeling and geospatial software must be resolved before 3D software will be broadly adopted by city planning departments and the general planning and urban design professions.

Wireless VR: Wireless VR would eliminate the need to hardwire and tether headset and controlling devices.

Sharing Files: Sharing 3D model files in a manner similar to Google Drive or Dropbox should be enabled in the future as the technology evolves.

Future Expectations

Architectural Engineering Construction (AEC) technology is currently moving toward a global integrated software environment. The first wave was the introduction of BIM software capable of integrating building and other data systems in addition to basic drafting and rendering tasks. The recent introduction of BIM into the GIS geospatial platform now provides planners and designers with the ability to use BIM information to design and analyze impacts on infrastructure and the public realm. The next generation of software will enable the inclusion of transportation and utility infrastructure systems (including surface and below-grade systems) with economic, social, and environmental performance measures, in addition to the building and public realm modeling capabilities now in place. The research team anticipates that the two systems will eventually integrate as a single platform for both geospatial and 3D modeling.