Middle States Geographer, 2016, 49: 74-83

3D MODELING IN LAND DEVELOPMENT PLANNING: A TOOL TO VISUALIZE CHANGE

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ABSTRACT: *Geospatial technologies have become well integrated into local development planning processes. Until recently, GIS applications have been two-dimensional in nature. With the advent of widely accessible three-dimensional geospatial technologies, local communities have a new tool to engage residents and other stakeholders in the land development planning process. We present how 3D modeling can be used in the land development planning process to visualize neighborhood redevelopment in a local community. The paper presents a preliminary assessment of the usefulness of 3D applications regarding ease of use and effectiveness for visualization of physical development standards.*

Keywords: 3D modeling, land development planning, zoning, visualization

INTRODUCTION

Local governments in Pennsylvania play a crucial role in determining future land development of their communities. Understanding the way, a plan will physically impact an area and its surroundings is an integral part of the land planning process. This is true across all fields of physical planning: transportation, land use, zoning, and comprehensive plans. Geospatial technologies have been widely employed to facilitate the land development planning process by demonstrating, among other things, the physical impact of proposed plans on a site and a neighborhood. Local governments have used two-dimensional GIS analysis and mapping extensively to visually illustrate planning proposals and demonstrate the spatial impacts of the proposed plans. Recently, local governments and planning agencies are turning to three-dimensional (3D) technologies to support land development planning efforts. There are many ways in which 3D technologies can be utilized in local planning. Models are said to provide municipalities with an effective and interactive visual approach that, if applied well, can result in improved analysis, stakeholder engagement, and better decision-making for public officials (Pettit 2006). Development regulations, especially zoning, are innately spatial. By providing richer visual representations of future landscapes, 3D models can play an iterative role in communicating development proposals and generating better public feedback. This paper presents an example of how 3D technologies can be integrated into a local land development planning process and demonstrates how these tools can be used for neighborhood-scale planning. Utilizing the latest 3D geospatial technologies, a comprehensive model was developed for a redevelopment area in West Chester Borough. The application demonstrates how 3D technologies can supplement 2D GIS capabilities in a local planning context. The model was evaluated to determine its effectiveness relative to 2D technologies as a visualization tool for land development planning at a neighborhood scale, and to assess its use in regard to ease of model development.

BACKGROUND

Suburban planning is largely regulatory. Compared to urban planning which involves large-scale planning of public spaces, planners in suburbs are predominantly regulators of the land development process. Their tasks include plan-making, regulating, largely with the use of the related tools of zoning and subdivision, and enforcing building codes. In Pennsylvania, most of the planning responsibility, including comprehensive plan development and land use regulation, is the responsibility of local governments (Pennsylvania Department of Community and Economic Development 2005). The planning and zoning process is made complex by the diversity of local stakeholders and conflicting interests. There are a number of people and organizations that are involved in the process of planning and making change in the suburbs, including governing bodies, planning commissions, zoning hearing boards, a variety of local boards, and other citizen groups.

Zoning is the primary regulatory tool that local communities have to implement development policy. In Pennsylvania, zoning is the responsibility of local government, and most local development planning concerns issues related to zoning. Zoning ordinances have evolved to incorporate a range of physical design and performance standards, but the three primary concerns of zoning include the use, density, and bulk standards related to development. All three elements are innately spatial. Geographic Information Systems (GIS) are widely used in planning for a range of analytical and mapping applications, including zoning. As a visual and spatial tool, GIS can be used to analyze, represent and communicate different planning scenarios, allowing planners, citizens and public officials to understand how zoning decisions will impact their communities. 3D technologies could be a useful tool over 2D applications if they can better communicate the spatial aspects of physical requirements under different zoning scenarios.

Until recently, most GIS applications for local development planning were two-dimensional. Outputs in two dimensions include flat maps, with spatial statistics pulled from various analyses that can be conducted on dynamic data. Two-dimensional applications are limited in their ability to apply and portray environmental constraints and the full spatial character of development standards in all three dimensions. This is limiting in a development-planning context as many development regulations, including building heights, setbacks, massing and density provision, are three dimensional in nature. 3D modeling can overcome some of these obstacles, by creating a comprehensive, to-scale model of an area in question, to better communicate the full spatial extent of development regulations. 3D technologies are particularly effective for communication, allowing the planner to present development standards to the public in a compelling, visual way. The newest GIS technologies have advanced to incorporate dynamic 3D modeling, with geographic information tied to the model, coupling spatial data with real-time ideas of what a development or neighborhood could look like.

There are many ways in which 3D models can be used by local suburban governments for planning purposes, but three stand out: 1) 3D models can be used to visually illustrate the spatial characteristics of zoning ordinance requirements; 2) 3D models can visually illustrate proposed development projects, and 3) 3D models can be effective in promoting community outreach and local engagement in the planning process. Zoning is innately complicated. It's complicated for all parties involved, including public officials, developers, planners, and residents. Local zoning requires specialized knowledge, specialized analytical skills, and contextual understanding of a neighborhood. Parties in the land development planning process are called on to understand the zoning map, the zoning code, the local development process, and how the three interact. 3D technologies offer a tool to communicate elements of zoning that are not easily portrayed in 2D formats, and to solicit informed feedback. The technology can be used to enhance discussions about zoning standards and requirements that have a 3D component, including height limits, setbacks, impervious coverage and density. 3D models can represent the spatial impact of a zoning ordinance in an area, demonstrating the way development built according to zoning will look visually and the implications of the ordinance on the immediate and surrounding environment. When a township or municipality anticipates changing or updating their zoning ordinance, a 3D model can be a powerful tool to help present conceptualized ideas by physically visualizing them. By understanding how a plan will look, and translating the words of a community plan into a navigable 3D scenario, plans can be created to be the most compatible that they can be with their surrounding areas. Visually, they are compelling, and therefore can effectively engage the community and facilitate public input.

LITERATURE REVIEW

Research on the effectiveness of 3D technologies for land development planning applications is limited. There is a growing literature on the concept of geodesign, a planning method that combines the creation of a design proposal with impact simulation information using a geographic context (Flaxman 2009). The field of geodesign, with the incorporation of 3D technologies, is new and quickly gaining in popularity. Geodesign allows for the sustainability of designs and plans to be evaluated before implementation, which is a valuable tool to planners (Flaxman 2009). In the past, maps have been used to express ideas and visuals in spatial planning (Eikelboom & Janseen 2015). As technology has progressed and evolved, geodesign tools have arrived at the forefront of collaborative planning as a tool with the potential to combine stakeholder values with diverse types of spatial information. Research is just beginning to assess their effectiveness in the planning process.

Communication is a key component of geodesign, allowing for multiple users to understand and digest a problem that may be difficult to put into writing or a 2D format. 3D models encourage greater communication and understanding, which in turn boosts public participation. Hanzl (2007) argued that new information technologies, specifically geodesign and 3D modeling, could enable citizens to be more involved in the planning process. In reviewing a range of applications including participatory planning GIS, 3D models, communication platforms, and computer games, the study found that in most of the new information technology reviewed, the systems focused on how they may be used for visualizing a new development, but fail to recognize how they may be used in public participation. Hanzl (2007) also argues that, despite the lack of emphasis, the greatest potential for incorporating 3D technologies into the public sphere lies in the use of collaborative software for participation of the public to get involved in urban planning. Eikelboom and Janseen (2015) investigated the communicative function of map graphics in planning and the effectiveness of geodesign tools. One of the main focuses of the research project was visualizing multiple stakeholder values at the same time, with a strong emphasis on communication. Comparing four types of geodesign tools to evaluate their effectiveness at visualizing multiple viewpoints and ideas, the study found that the tools used in geodesign practice should be as simple as possible, and that adding advanced functionalities made the tools more complicated. Simplicity often lends itself to greater communication, with fewer barriers to cross.

3D technologies have been found to allow for higher levels of creativity and experimentation, and take into account the environmental constraints of an area. Investigating the use of 3D models in developing the Chicago central area plan, Al-Douri (2009) found that using the technology resulted in increasing the design detail and design content of a plan, as planners were able to communicate different elements. The study also found that 3D models improved the quality of the decision-making process by increasing users' cognitive and communication abilities by providing a platform for efficiently coordinating across multiple groups involved in the planning process.

Plans require a high level of functioning analytical and statistical work. 3D geospatial technologies enrich traditional planning and design by combining the power of modern computing, communications, and collaboration technologies (Ervin 2011). This collaboration requires the integration of various types of data, software, and multiple systems. Geodesign is multi-disciplinary across a range of domain areas, making it a versatile tool in planning. Traditional data layers provide a 2D base for presentation, while most elements have a variety, or hierarchy, of 3D objects that are presented as a plan. Utilizing the new support given by modern computing and communications technology is an important aspect of this new level of geospatial analysis.

A recent study done by Kim, Kang, and Han (2014) proposed a framework that automatically generates a textured, high-resolution 3D city model that can be used for ground-level applications. They argue that existing, large-scale 3D city modeling methods do not provide rich visual information at the ground level, failing to provide for more diverse areas which require higher levels of detail (Kim, Kang, & Han 2014). To complete the framework and model, a mobile mapping system (MMS) was used to automatically gather high-resolution images and GIS data, and was then integrated with 2D imagery and base models using MMS data. They focused on very high detail modeling, which can be effectively utilized at the ground view.

A study done by Ki (2011) puts emphasis on the development of a ubiquitous city (u-city) using a web-GIS system. In the past, u-city development focused primarily on building the physical infrastructure of a city into a 3D model. Ki (2011) suggests the addition of real-life modules to the physical infrastructure would be effective for local governments involved in urban planning, citizen participation, and city marketing. The author demonstrates how the system can become a tool to encourage public participation through public information sharing, sustainability analysis, urban physical planning, environmental planning, citizen participation, and city marketing. Billger *et al* (2016) reviewed research regarding visualization as a dialogue tool. They concluded that the use of technologies, such as 3D modeling, are dominated by top-down approaches. The trend has worked from prototyping and experimental applications towards the utilization of these tools in the planning process. Studies of the impact of these tools upon the process and community engagement are rare.

This research contributes to this body of literature by investigating the potential application of 3D technologies in a suburban land development planning context.

PROJECT AREA AND PLANNING CONTEXT

West Chester Borough is an independent local municipality and county seat of Chester County, Pennsylvania (Figure 1a). With a total area of 1.8 square miles and population of 18,461 residents, West Chester is a relatively dense, urban center in a suburban region (U. S. Census Bureau 2016). Culturally, the borough values its historic town character and strong social networks, while striving to incorporate modern amenities to attract a diverse community that values a town center environment. The Borough has made a significant investment in protecting its historic downtown. A diverse population lives in the Borough, ranging from older retirees to young professionals to college students attending West Chester University, which is located almost entirely within the municipality's borders. Protecting the historic character and town scale while providing for strategic growth has been a challenge of planning in the borough, and the local government works hard to maintain West Chester's historic character while planning for a sustainable future. Development in the borough is regulated by eight zoning districts, supplemented with three overlay districts.

The Borough began a two-year process to update its comprehensive plan in 2005. Comprehensive plans are policy documents used to communicate the development vision of a community and provide land development guidelines. While the Pennsylvania Municipalities Planning Code (MPC) limits their legal standing, comprehensive plans in Pennsylvania are intended to serve as the basis for municipal zoning ordinances and subdivision regulations. Most of the Borough of West Chester is developed, but there are areas that are suitable for redevelopment. As part of the comprehensive planning process in West Chester, four areas were identified as locations for substantial change (Figure 1b). Called "Future Enhancement Areas," they are areas likely to experience substantial development or redevelopment in the future, most likely in the form of mixed-use development consistent with the existing scale of the Borough and pedestrian character. The existing zoning in the four enhancement areas did not support the type of development envisioned by the community. New zoning standards need to be adopted in the targeted areas in order to implement the new development envisioned in the comprehensive plan.

One of the Future Enhancement Areas was chosen as the site for this project. Called the *Gay/Market East Corridor* by the local community, the area aligns with a zoning district called a Commercial Services (CS) District. Located at the eastern edge of the Borough, the CS District, (one of two areas in the borough zoned this way), is located just outside of the downtown commercial center of West Chester. The purpose of the CS District, as stated in the zoning ordinance, is to accommodate highway-oriented commercial uses directly outside of the Town Center District. Over time, the corridor grew to accommodate automobile-oriented uses such as service stations and fast food restaurants. The Borough hoped to encourage new development in the corridor that would be consistent with the existing historic and pedestrian-oriented character of the adjacent downtown. Ripe for redevelopment the area presented an opportunity to reimagine how it could be rebuilt, and a good test site for 3D geospatial applications.

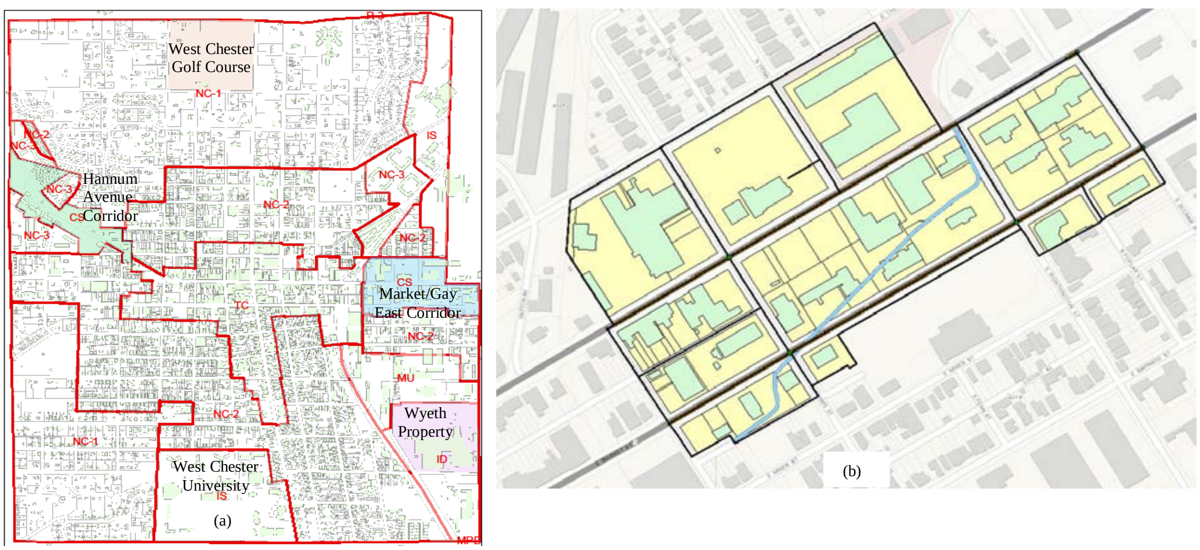


Figure 1. (a) West Chester borough with commercial service districts (CSD). (b) Market/Gay (CSD).

PROJECT DEVELOPMENT

The modeling project itself had three main objectives: 1) demonstrate how advanced GIS applications can be integrated into West Chester Borough's land development planning process, 2) create an actual GIS-based 3D model based on current zoning standards that could be used for planning, and 3) assess how the platform might be used for community engagement and participation around development planning. This section describes the basic project development steps.

Data Collection and Analysis Procedures

The study was conducted at the parcel level in West Chester Borough. Data was collected using Chester County's Open Data Portal, and included: parcel lines, building footprints with height information, road centerlines, township boundaries, and zoning districts. These shapefiles were imported into a geodatabase to be compatible with software data requirements. Along with these spatial layers, rule files were brought in from CityEngine's base project files and edited using the computer software, CityEngine.

Software

Two of ESRI's software packages were used to develop the project and explore the 3D workflow. ArcMap is a geospatial-processing program used to view, edit, create, and analyze geospatial data. This program is one of the most commonly used, and does not incorporate 3D technologies, well. However, ArcMap was used to process and edit the data, preliminarily, in order to be used in the 3D program, CityEngine. Some of the functions used in ArcMap include preparing aerial imagery and a Digital Elevation Model, edits to the attribute table in various data sources to make them legible and functional in CityEngine, creating a File Geodatabase, and clipping the data to the specific study area. ArcMap's visual tools were helpful in creating basic 2D maps by symbolizing the data for meetings with the borough to identify the study area.

CityEngine was the primary software used in this project. Defined as 3D modeling software for urban environments, it can be used to transform 2D GIS data into smart, 3D city models. CityEngine was originally developed for creating city landscapes very quickly and with mass randomization. ESRI bought the software in 2011 and worked to better integrate it into the GIS workspace, which entailed getting it to focus less on randomization and more on real-world infrastructure. One of the major components of this modeling system that sets it apart from software packages such as Sketch-Up and AutoCAD is that it uses a procedural modeling core to build flexible scenarios. Procedural modeling is driven by rules that can be customized to use personal textures and 3D assets, but also allow for the use of predefined rules that enable instant creation (ESRI 2016).

As noted, the Commercial Services District on the eastern side of the borough was selected as the project area to model with CityEngine. For the purposes of this project, only principal uses identified in the current zoning ordinance were used to create the model. If needed, conditional and other uses can be added, at a later date. The permitted principal uses of the CS District include: retail stores and shops, wholesale stores and distributorships, restaurants and fast-food restaurants, personal service shops, offices, automotive sales and service facilities, car wash facilities, clubs or lodges, motels, public service facilities, municipal uses, and commercial parking lots. The CS District requires off-street parking to accommodate these uses.

In addition to uses defined in the zoning ordinance, area and bulk requirements, such as height regulations and setbacks, were also taken into account. Area and bulk standards are summarized in Table 1.

Table 1. Area and bulk requirements CS district.

STANDARD	
Maximum Building Height	35 feet
Minimum Lot Area	7,500 square feet
Minimum Lot Width at the Building Line	100 feet
Minimum Lot Width at the Street Line	75 feet
Front Yard	15 feet min; 20 feet max
Minimum Rear Yard	35 feet
Minimum Side Yard	20 feet
Minimum Setbacks for Parking and Loading	15 feet
Maximum Building Coverage	60%
Maximum Impervious Coverage	85%
Maximum Green Area	15%

Additional select design standards from the zoning ordinance were also incorporated into the CityEngine model. The borough requires buffer planting strips with a minimum of eight feet in width to be installed along any abutting side or rear lot line. Other design elements include making the streets more pedestrian and bike friendly by implementing complete street and streetscape improvements.

Completed Model

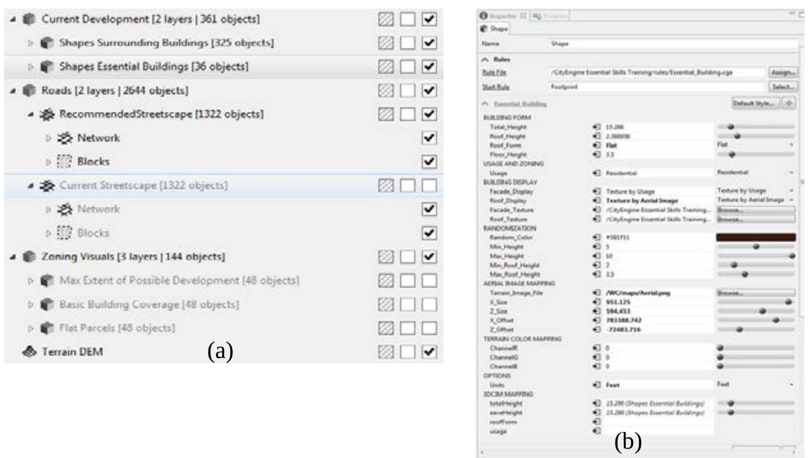
The final model of the Commercial Service District in West Chester Borough is made of thirty-six buildings located within the CS District, which are surrounded by 325 less-detailed buildings for context. The road layer is comprised of 1,322 line segments. The model is overlaid onto an aerial image, which represents the terrain within the model. There are a total of eight layers in the final model output. The layer "Essential Buildings" and "Surrounding

Buildings" are building footprints, modeling the current infrastructure. The layer “Max Extent of Development” is created from a parcel layer, and represents the maximum build out of parcels based on existing zoning standards. “Basic Building Coverage” is similar to the Max Extent of Development, but provides a more simplistic view and will provide reports (Figure 2a). There are two street layers. The first is a Recommended Streetscape, with a high level of detail including recommendations for street improvements to be more pedestrian and bicycle friendly.

Existing Infrastructure/Buildings

Two layers comprise this part of the model: essential buildings and surrounding buildings. Both layers were created using the building footprints layer imported into CityEngine in the file Geodatabase. Included in the building footprints layer was the height of each building. The difference between the two layers is detail: essential buildings have more personalized and exact detail to represent the existing buildings. The surrounding buildings layer is used to provide context outside of the CS District, and do not have as much detail.

To create these buildings, the “Essential Building.cga” rule was applied (Figure 2b). This rule provides many different functionalities and customizations. In addition to customizing each building with the appropriate rule file/options, the aerial imagery used in the terrain was then used as a texture file to overlay on top of the building footprint to give them a higher level of detail.



Figures 2. (a) Model spatial data layers. (b) Rules definition for 3D building models.

Complete Streets

The rule layer used to create and customize the streets layer was the “Complete Streets.cga” rule. This comprehensive rule allows complete customization, including road width, sidewalk material, and extra features such as street trees and even car models. The road layer was created to be a representative “streetscape” for the CS District. The streetscape included trees and sidewalk improvements recommended in the Borough’s Comprehensive Plan. The streetscape model allows planners to easily demonstrate landscape changes and scenarios (Figure 3).

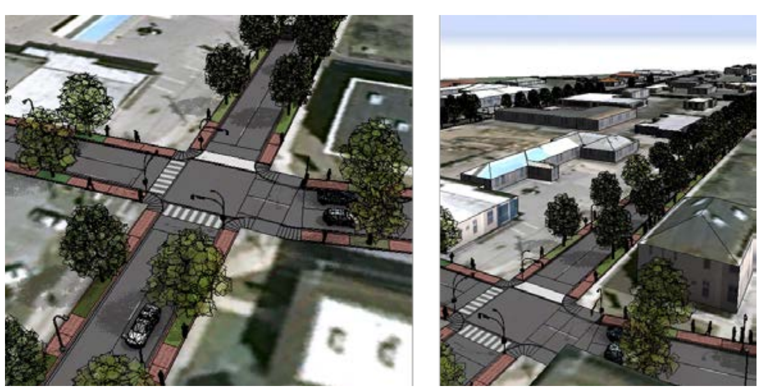


Figure 3. Enhanced streetscape model.

Zoning

Another feature added into the model was a layer representing the current zoning of the CS District. The zoning layer was created using the parcel layer of the CS District. The "Max Extent of Possible Development" layer uses the Parcel.cga rule, which was created to show the "envelope" of zoning extents within parcels. It was edited to include the current max and min extents of setbacks and height limitations (Figure 4).

Figure 4. Maximum development potential.

Final Export

The final model in the CityEngine interface can be seen in Figure 5a, below. Using this model, participating Borough representatives were able to adjust zoning and local ordinance parameters (height, setbacks, parking, etc.) to evaluate different development scenerios. In addition to having the model available using the software, the model was also exported to a CityEngine WebScene (Figure 5b), where it can be viewed by stakeholders as well as commented on by the general public. This allows for greater collaboration and transparency.

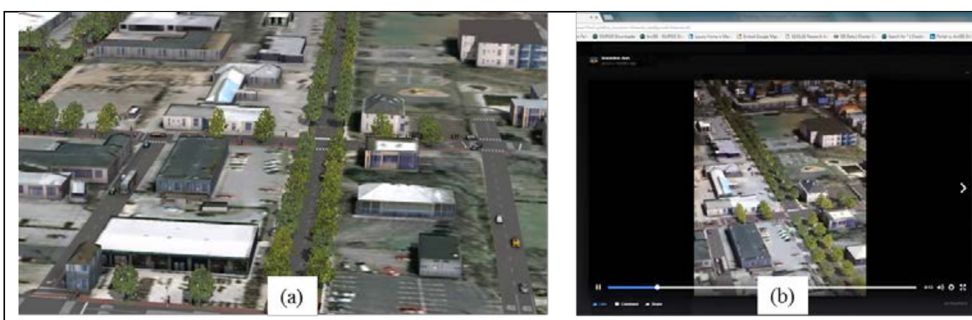


Figure 5. (a) Final model. (b) WebScene.

ASSESSMENT

The completed project provided a comprehensive 3D model of the Market/Gay East Corridor. The model provides an effective visualization of what currently exists, along with the possibility of what could be developed under differing zoning scenarios. By testing different standards and presenting their full spatial expression, the 3D model can serve as a tool for many major discussion points for borough officials and the public around the full spatial extent of potential development, providing a starting point for considering future redevelopment and imagining the possibilities of the CS District. The existing surrounding area and existing infrastructure provides a real-world context to the CS District and allows a realistic assessment of possible projects within this area of the borough. Together, the three main layers of buildings, streets, and zoning work to show the full physical potential of the current zoning ordinance, and the impact of modification of any of these standards. Visualizing the impacts in 3D is a significant enhancement over imagining the changes in a two-dimensional environment. The enhanced visualization can serve as an important tool to develop and work with new ideas.

The model was shared with certain key borough officials, but has not yet been tested with residents and other stakeholders. The key stakeholders included the Borough Manager, the Borough Zoning Officer, two members of the planning commission and two members of the Borough Council. Specifically, they were asked to provide feedback on the usefulness of the Enhanced Streetscape and Maximum Development Potential models for engaging the community in visualizing the impact of a proposed zoning change in the district. All agreed that the Maximum Development Potential model would be useful to communicate the spatial extent of key dimensional characteristics including building coverage, height and massing, as well as the spatial impact of different lot setback requirements on the streetscape. They also agreed that the Enhanced Streetscape Model would provide a useful visualization regarding potential streetscape improvements, which would likely require some amount of public funding. There was concern that Maximum Development Potential model would trigger additional community concerns related to the increased density, such as traffic. There was also concern that the relative simplicity of both models would generate additional concerns regarding the architectural characteristics and other specific design standards that are not adequately portrayed on either of the models.

The trade-offs suggested, in the key stakeholders responses, are consistent with recent research that investigates the usefulness of geospatial tools for decision-making. There are recognized challenges related to the use of geodesign and other geo-spatial techniques to address issues in a collaborative decision-making environment such as planning. Planning problems have social, emotional and political dimensions that require complex assessment approaches (Eikelboom and Janssen 2015). Individual stakeholder behavior and reasoning in planning and other public decision-making settings is driven by a complex set of internalized values, which defy standard assessment approaches. Recent research explores how new technological and scientific tools affect the social process when they are used in practice (Opdam *et al* 2013)). A full assessment of all stakeholders requires accounting for multiple rationalities, and while it is beyond the scope of this paper, it is an important next step to identify the most effective uses for the tools.

Some limitations to the project involve the complexity of the programming required, especially the development of the zoning rules. Editing and creating rules requires a strong background in programming, while learning an entirely new language. It is difficult to produce new rules from scratch. New rules were experimented within the model, but ultimately weren't used due to limitations with the robustness of the rule interface. Rules that were already created can be edited, but require a deep understanding of the rule-building procedures and the language surrounding these rules. Building up a library of rules would be beneficial to any agency looking to implement 3D technology. In the end, rules were edited to suit the purpose of the model and project in order to crete a prototype modeling environment.

3D technologies are innately complex and made more challenging to master due to the ever-changing nature of technology, the supporting data, and hardware demands for 3D visualization. In order to best employ the technology, either individually or within an organization, it is necessary to develop detailed workflow guides. A full workflow was developed and tested for this project.

DISCUSSION AND CONCLUSION

This research project involved the development of a 3D model in a section of West Chester Borough and an evaluation of the model in regard to its usefulness in visualizing a proposed zoning change. In addition to providing effective visuals, the model demonstrates how 3D models using spatial information are able to perform authentic, realistic analyses and feasibility studies based on specific zoning standards or development proposals. Modeling environmental processes such as storm water run-off, impervious surface coverage, and sunlight exposure, using 3D models, can comprehensively anticipate the physical impacts of a community plan on the area before the plan is adopted or implemented. These processes are also scalable, allowing models to identify the impacts from a range of development types from very large projects, such as a residential neighborhood subdivision, to a one-office building addition, or an entire town.

Advanced geospatial technologies have strong potential to engage the community by providing a platform to present ideas to the public as part of the planning process, enable participation, and ultimately help planners make more informed decisions on planning design elements. 3D models have the potential to bridge the gap between local government agencies and the public, allowing the highest level of transparency available. The technology puts the power into the hands of the planning commission and the public, enabling both to easily test scenarios, provide feedback, and thereby to be creative in their decision-making. Different parties in the planning process have opportunities to cross boundaries and try new planning techniques that might have been considered unfavorable in the community. It provides transparency, while also promoting creativity and exploration.

While they are by nature very complex, 3D technologies are on the rise in planning commissions and agencies across the world. As the costs of utilizing the technologies are reduced and they become more user-friendly, it is expected that they will become an integral part of the planning process. This research project demonstrates the potential application of 3D modeling to a current planning exercise in West Chester Borough, and suggests the advantages of the technologies in the local planning process. 3D technologies can be useful in demonstrating the impacts of zoning ordinances and visualizing development proposals. As a communication tool, they can be effective in engaging the local community in the development planning process. Other uses that are likely to become more prominent in the future include modeling build out scenarios, modeling land use plans, and the addition of virtual reality tools to further visualize change. Local governments need to pay attention to the evolution of these technologies and their potential applications. Incorporating the technology into the planning process can be effective in better communicating the impacts of proposed developments and regulations and thereby better engaging the community in discussions about proposals, without being overwhelmed by the supporting technology platform.

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