INTERACTIVE VISUALISATION TO SUPPORT SUSTAINABILITY ASSESSMENT IN LAND USE SCENARIO PLANNING

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Real-time interactive 3D visualisation of GIS data is becoming increasingly important in the fields of regional and local land use planning, sustainability assessment and energy efficiency monitoring. Turning expert GIS based data into something useful, recognisable and digestible by non-expert stakeholders is a challenging task as participants from different cultural and educational backgrounds must intuitively access the information presented. Stakeholder engagement in land use planning scenario development is critical to enhancing the sustainability of a given project. The use of decision support tools can provide a solution for engaging both expert and non-expert stakeholders. Various real-time decision support tools (DST) have been developed in the past, and recently using programming libraries and frameworks originally developed for commercial video games. In this paper we present a case study where an interactive 3D decision support tool (LEX 3D - Landscape Explorer 3D), was developed to provide a visual impact assessment of proposed housing developments which users can easily locate and change the components of - i.e. layout of the housing within the development, roads and communal green spaces. Additionally, LEX 3D is able to compute and visualise sustainability indicators (e.g. night time street lighting, energy usage and land use ordnance survey data visualisation). We will discuss the steps necessary to streamline GIS data for display in interactive visualisations. We will highlight the games technology techniques implemented that help promote better stakeholder engagement. We conclude that the use of games based decision support tools for planning and sustainability assessment purposes can potentially benefit engagement of non-expert stakeholders.

Keywords: visualisation; strategic planning; sustainability; computer game; stakeholder engagement

INTRODUCTION

The use of interactive visualisation based on computer games technology has recently gained widespread popularity for use in scientific, medical, educational, geographical and land use planning disciplines (Bown *et al.* 2010). The flexible and robust nature of game development frameworks and engines allows for rapid application development methodologies to be applied in terms of solving real-world planning and visualisation problems. Participation of both expert and non-expert stakeholders is crucial in any planning process, as is the ability to transparently communicate information between

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all of the involved groups. Active participation of stakeholders in land use planning scenarios can be accomplished through the use of custom interactive decision support tools, allowing the stakeholders to explore, interact and observe the impact of proposed changes of the visualised scenario. Scenarios using 3D interactive visualisations as a means of communication can explore layouts of proposed housing developments, energy usage, green space usage, simulation of artificial night-time lighting conditions and larger scale visualisation scenarios - such as the visualisation of a proposed waterfront development in the city centre of Dundee, Scotland (Isaacs *et al.* 2010). In this paper we will discuss the development and use of a custom interactive 3D decision support tool called LEX 3D (Landscape Explorer 3D). We will also discuss using 3D visualisation to promote wider engagement and discuss how this type of tool can support the planning context and the development of low carbon housing.

SUPPORTING LITERATURE

Support for wider public engagement and community planning was advocated many years before computer based decision support tools became available. The Skeffington Report (Ministry of Housing and Local Government 1969) promoted the view for helping the general public to participate in key planning stages of proposed town developments. In a published report by (Wynne 1992), the argument for full transparency of the policy making process, involving both experts and non-experts is defined. This argument suggests that scientific fact should be presented to and debated by all involved stakeholders - without being concealed or obscured by those with more knowledge about it. A decision support tool or system can provide a solution to this problem. The main objective of a computer based interactive decision support tool is to be able to visualise complex scientific data, and re-interpret it visually to the stakeholders so that it can be used to identify potential concerns - thus democratising the planning process. An interactive decision support tool can be used to visualise key aspects of development proposals, during various stages of the planning process.

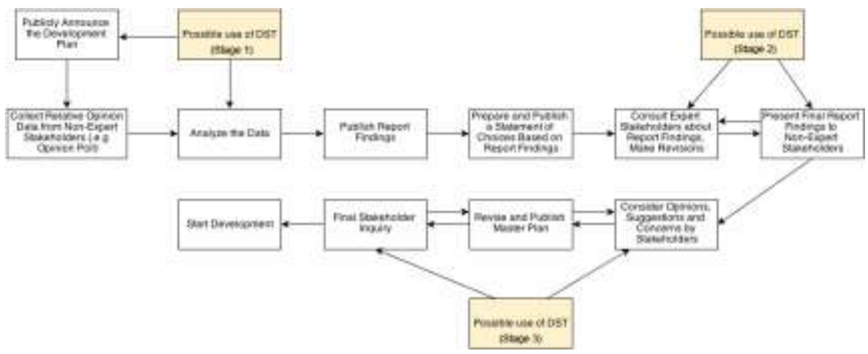

Figure 1: Example of how a decision support tool can be used at various stages during the local planning process.

Expert and non-expert stakeholder use of interactive decision support tools can be implemented during the three stages of planning as outlined by the Skeffington Report: the structured planning stage, the public discussion stage and the local planning stage. Non-expert use of such tools can be especially beneficial during the local planning stage, as the tool can be used to replace dated non-interactive presentation mediums (e.g. drawings, films and videos of the proposed development) -

with a more interactive and engaging experience. This can help create a transparent communication layer between the involved parties, as well as to create a testing protocol for visualising sustainability concerns in the short, medium and long terms. Figure 1 shows an example of local planning stages where a decision support tool, such as LEX 3D, can fit into (and potentially benefit) the local planning process. While decision support tools were originally developed for expert use (Kapelan et al. 2005), over the years a clear need for including users from a wide field of professional, educational and social backgrounds has become evident as a way of further gauging public interest in project proposals for regional and local land development. This creates a wider sense of inclusion, awareness and general interest within the involved communities - and can help strengthen the relationships between the involved development contractors, the local councils and the general public (thus strengthening social, economic and political ties within the community) (Appleton 2004). Research carried out by (Al-Kodmany 1999) highlighted the importance of community engagement with urban planners, and described the use of a decision support system that allowed for the unification and presentation of both expert and non-expert data between all those involved in the planning process. The conclusion of the case study highlighted the benefits of community engagement in the planning process, as well as the use of local expertise that might have otherwise been neglected by expert stakeholders. Research carried out by (Kaatz et al. 2006) describes “three significant outcomes” of building sustainability assessment – which include: integration, transparency and collaborative learning and engagement. The use of interactive decision support tools fits into these three outcomes - as it facilitates integration between ideas, issues and concerns of expert and non-expert stakeholders; provides a transparent communications platforms by means of utilizing interactive non-expert comprehensible data visualisation methodologies; and allows for collaboration between expert and non-expert stakeholders by allowing experts to draw from local knowledge of non-expert stakeholders, and in turn to communicate expert knowledge based results, conclusions and concerns. A good example of early research concerning the benefits of using virtual and interactive 3D GIS systems was covered by (Koller et al. 1995).

The research demonstrated the successful use of their 3D GIS system for visualising the topography of terrain data for operations planning use by the United States Army. This showed that the 3D GIS system could be used to plan critical tasks in real-time. Research by (Bishop et al. 2000) highlighted the importance of then emerging “virtual environments” technology. The reason why this study is of particular interest is because it was published at a time when 3D capable computer hardware was entering the mainstream consumer market (especially after the emergence of interactive 3D games near the end of the 90's). Most average non-expert users at that time were not overly familiar with concepts of 3D virtual environments, thus the fact that the study provided supportive evidence of using a 3D virtual reality system for public engagement creates a good starting point in history for the emergence of what we now refer to as interactive 3D decision support tools. Subsequent research by (Lange 2001) focused on user visual preference and showed that non-expert users assigned a very high visual impact value to simulated 3D scenes in comparison to their photographic reference images. Additionally, research carried out by (Zlatanova 2002) provides a comprehensive review of what we can refer to as the first generation of commercial 3D decision support tools. A decision support tool that is interactive; can be used by both experts and non-experts; can communicate vital planning and sustainability information in an intuitive manner; can optionally support multiple users at the same time (Ball 2007) and can be used on average consumer level computer hardware – would in no doubt greatly benefit a given land use planning and sustainability assessment process. Recent research by the Abertay SAVE group (Isaacs et al. 2010; 2013) provides detailed evidence for supporting the research, development and real-world use of such tools - using games-based technology.

METHODOLOGY OVERVIEW

The Case for Using Games-Based Software Development Frameworks

With the advancement of interactive real-time 3D rendering technologies around 2001 - mostly based on the introduction of consumer level programmable graphics hardware, - new and easier to use software development tools for developing interactive 3D applications emerged (Wright *et al.* 2007; Moller *et al.* 2008). Most of these software development tools were game engines and frameworks, aimed at facilitating and accelerating the development of 3D games applications. While these games based software development tools were originally designed to create games on various different hardware and software platforms, their general flexibility and robustness soon caught the attention of software developers involved in virtual reality, training and simulation software development (Lewis and Jacobson 2002; Friese *et al.* 2008). By their nature, games engines and frameworks are designed to leverage the object oriented approach of software development (McShaffry *et al.* 2009). A game system can be divided into two distinct component groups – data and logic (DeLoura *et al.* 2000). The logic group contains code components – functional pieces of software code that are executed during the run-time of the application in order to instruct it to compute the desired result. The data group contains the data used by the logic components in order to compute the final desired results. The data components can be anything from 3D CAD models, vector shapefile data or environmental and meteorological data. A given game engine will often attempt to treat the collectively merged code and data groups as single entities. This provides a benefit of using coupled data and logic to dynamically modify the needs of the scenario during the run-time of the simulation, and enables the re-use of these objects in different scenarios. Additionally, a given game engine system that is used to develop an interactive decision support tool is able to implement the requirements for visualisation outlined by (Mach and Patschek 2010). These requirements are defined as the "Five Principals", and can be summarized as:

Representative Character – What important topics/problems does the visualisation address.

Exactness – The visualisation should be able to visualise the given scenario to an acceptable level of visual and scientific accuracy.

Optical Clarity – Specific aspects that are of visual importance in the given scenario should be instantly recognizable by the viewer/user.

Interest/Engagement Factor – The visualisation should be able to immerse and engage the viewer/user.

Legitimacy – The need for and the exactness of the visualisation of a given scenario needs to be justified.

The application of games technologies to visualisation of land use planning and sustainability is a beneficial and viable solution for meeting both long and short term project specification requirements.

Overview of the Research Development Cycle

The Landscape Explorer 3D (LEX 3D) decision support tool was developed using the Microsoft XNA games technology framework. The use of XNA allows for rapid application development of custom games components that could be used to create interactive 2D and 3D games, visualisations and applications. The XNA technology itself is not a games engine - but rather a collection of code functions that eliminate the need to rewrite the minimum requirement components of a 3D application for the Windows platform. The use of previous versions of this games technology had a proven track record - as an older version of XNA was previously used to successfully implement the requirements specification of the S-City VT project (Isaacs *et al.* 2010). One of the initial and major difficulties encountered when the LEX 3D project was started was the problem of dealing with non-standard GIS and CAD data types, which were used to store various 2D and 3D data components required for the interactive scenarios. The solution to this problem was solved by utilizing various pieces of third-party open source and commercial software tools that are used within the GIS and CAD communities. Using these software tools the data was converted into standard 2D and 3D file formats that could be parsed using XNA into the LEX 3D framework. The converted data included ordnance survey data, shapefile overlays, satellite and aerial photography images, 3D models of the houses and the surrounding environment and the corresponding texture images for the 3D models. The second problem that was encountered was calibrating the spatial accuracy of the GIS data. The solution to this problem was accomplished by comparing the spatial properties of the original GIS data, using a specific GIS software tool, to the spatial coordinates of the parsed GIS data in the visualised scene. All of the comparisons were performed visually, thus there is a slight amount of spatial inaccuracy present in the parsed GIS data. However, as pointed out by (Mech and Petschek 2010), this is a normal consequence of trying to visualise (and essentially scale down the complexity) of specific and non-standard GIS and CAD data. Figure 2 illustrates the process model that was followed in order to successfully implement LEX 3D.

CASE STUDIES

This section highlights two case studies where LEX 3D was used in order to visualise parts of the planning process (stages 1 and 3 of the diagram in Figure 1). LEX 3D was initially developed to meet the needs of the requirements specification that was proposed by the Fife Council Enterprise Planning and Protective Services in mid-2012, and refined during the development cycle of the project through subsequent meetings. The initial project phase lasted around six months, with the first version of LEX 3D being completed in November 2012. The second case study that is outlined describes the use of a more recent version of LEX 3D for visualising smaller scale housing developments - with a focus on visualising solar-gain sustainability indicator models. This version of LEX 3D is currently being developed for use by Lundin Homes, who are acting as the main clients. This provides an interesting perspective on the capabilities of using decision support tools in terms of how they fit in during two different stages of the typical planning cycle.

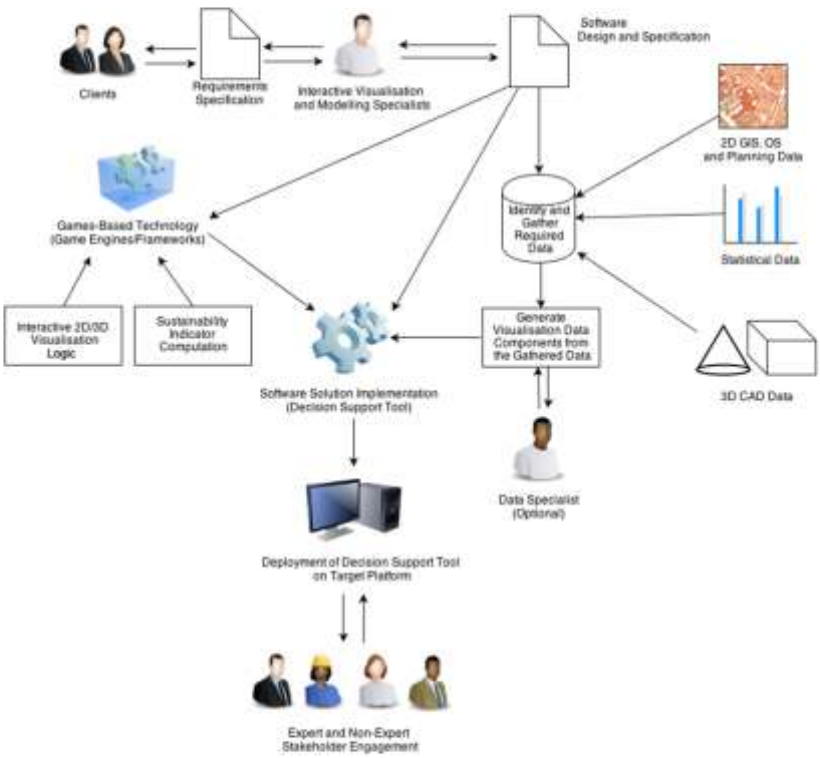

Figure 2: The development cycle model used to create LEX 3D.

Medium Sized Housing Development

The current version of LEX 3D is capable of visualising different aspects of housing design at pre and post master planning levels. The initial version of LEX 3D was used to visualise the entire region of Fife on a very large scale, and was mostly used to demonstrate the tools interactive visualisation capabilities. After this initial demonstration, a decision was made to refocus the tool and to place emphasis on a proposed suburban development called Dunlin Drive (a suburban residential area in Dunfermline, Scotland). The development at Dunlin Drive is marketed as an affordable housing estate for first time home buyers. The area of Dunlin Drive comprises of several types of eco-homes and the tool allows the construction firm a development view of energy efficiency assessment in terms of U value visualisation. It also guides the estate layout in terms of where to place street lights for a well-lit development that is acceptable to potential residents. LEX 3D can also be used to contextualise the development in terms of access to existing services by merging the 3D view with exiting larger scale GIS data. This could be applied at the master planning stage and post master planning stages for communicating a sense of place. The public housing contractor Kingdom Housing was responsible for the development of the houses on the site, and they provided the team at the Abertay University SAVE group with architectural drawings and relevant ordnance survey data. The development team at Abertay University was composed of one full-time software development staff member working on LEX 3D (the first author of this paper), one part time computer arts specialist (who was responsible for creating the 3D models of the houses and the surrounding environment), and four full-time supervisors who provided feedback and guidance during the development cycle of the project. The initial release version of LEX 3D took about 400 hours of work to complete between the full-time software developer and the part-time computer artist.

Spatial location and type of buildings

In LEX 3D the users are able to select given 3D objects in the visualised scenario, via the use of a mouse and keyboard, and dynamically alter their spatial values in real-time. Users can change the size, translation and rotation of given 3D objects in the scene that are of importance (such as houses, trees and lamp posts). Another key feature of LEX 3D is the visualisation of the communal play park and green space areas in Dunlin Drive. Research carried out by (Byrne and Sipe 2010) stresses the importance of integrating green-space areas within communities. Planning the location of the proposed communal green-space development requires the input from those who are members of the community. Thus being able to visualise green-spaces and to edit their spatial properties plays a very important role in communicating across points of mutual understanding between the developers and the community. Users can additionally move around the scene with six degrees of freedom (referred to as "flying" around the scene) and walk around the virtual representation of Dunlin Drive (where they can navigate the development from a first person street level point of view). The ability to fly around the scene and to be able to "look into" the proposed development - from a nearby hill for example - was a feature that was specifically requested by the clients. The clients were interested in being able to look into the proposed development and to see how the much of an elevation offset each house had in relation to each other, based on their location at different elevation levels on the development site (essentially simulated line of sight land surveying). The line of sight viewing feature was implemented in LEX 3D by allowing the users to move around the scene and to toggle the "offset value based" vertical positions of the house models in the development site - based on extracted land contour ordnance survey data that was provided by the clients. Additionally a ray vector could be projected from the users view or a specified location, to another location in the scene, allowing the users to observe all of the intersections in-between the two points.

Energy Efficiency Visualisation for Different House Types

The house type specific energy usage visualisation module is able to visualise the U-values and overall heat-loss values of the key construction materials for different parts of the house models in LEX 3D (such as the roof, walls, doors and windows), as well as the overall Standard Assessment Procedure (SAP 2009 v9.90) energy rating for the specific house types. The combination of these energy visualisation methodologies can be used to visualise and assess the impact of various housing energy models (Asseln-Miller and Douglas 2010). The U-value, heat-loss and the standard procedure assessment values were based on empirical test data for various sustainable house construction material specifications (e.g. Passivhaus). The general heat-loss equation used is defined as (Weisstein 2012):

$$Q = U \cdot A \cdot \Delta T$$

In the implemented model, the inside and outside temperature difference ΔT is kept at a constant value (but for non-demonstration purposes, this value can be changed dynamically), and the total surface area A is calculated for each relative polygon group of the 3D house model. The heat loss model material U-values were based on the material U-values and energy ratings data provided by the client. These values were mapped onto the given object surface using a suitable visual indicator in the form of a gradient map with corresponding values (see Figure 4 for examples).

Simulation of Night-Time Street Lighting

The visualisation of the night time lighting conditions was another feature that was added in order to allow the members of the community (and potential house buyers) to observe and navigate the proposed housing development during different times of the day. This is important as a sense of security, and awareness of ones surrounding during the night time is affected by the lighting conditions (Welsh and Farrington 2008). A common lighting model that is used in real-time rendering to model focused light volumes (such as those generated by street lights), is the spotlight model. In most 3D graphics applications, a spotlight is an entity used to describe a conic light volume. A spotlight is defined as a cone with a variable base and cut off radius, where the intensity of a spotlight is controlled by an exponential control variable (Moller *et al.* 2008).

Land Use Shapefile Indicator Overlay Visualisation

The final feature that was implemented was the rendering of 2D shapefile data overlays. The 2D shapefile and ordnance survey indicator overlays allow expert stakeholders to get a better sense of how well the development is connected to existing services and to highlight possible problematic areas in terms of congestion (and lack of), as well as to communicate with non-expert stakeholders how the proposed development area impacts the current layout of effected and surrounding land areas (Meeda *et al.* 2007; Chan and Bishop 2007).

Small Low-Carbon Solar Gain Oriented Housing Development

A new visualization module of LEX 3D is currently being developed for use by Lundin Homes, as part of their low carbon footprint sustainable housing planning process. This version of LEX 3D is being used to maximise and visualise solar energy gain as opposed to energy loss; this tool would be used at the master planning stage. Passive solar gain plays an important role in the development of new sustainable housing, as it can reduce the overall energy usage for a given home (Asseln-Miller and Douglas 2010). Apart from the materials that are used to build sustainable homes that affect U values as described above, two other important factors that affect the overall solar gain are the position and the shape of the houses (Walker 2009; Caldas 2007). Being able to find the optimal shape (via the use of a genetic algorithm) and spatial location to build a sustainable home provides an opportunity to use interactive visualisation tools. This is an emerging area of research as it is only now that games technology tools have become powerful enough to simulate accurately the sun rays and surface exposure as a consequence of landscape topography, neighbouring buildings objects and meteorological data. The interactive visualisation module of LEX 3D has been extended to make use of real-time ray-tracing methods (Moller *et al.* 2008) - in order to accurately model the amount of light absorbed by the houses based on the position of the sun during a specific time of day, as well as to accurately model the resulting shadow volumes.

CONCLUSIONS

This paper has presented the benefits of using interactive 3D decision support tools for expert and non-expert stakeholder engagement. Strong evidence was provided that shows favourable support for using interactive decision supports tools in order to aid sustainability assessment and town planning applications through expert and non-expert stakeholder engagement. An overview of two case studies shows where the LEX 3D decision support tool has been and is being applied to aid the pre and post master planning stages of the land use planning and development process. The use of game technologies applied to environmental science and planning is a growing field and with the standardisation and mandatory use of the Building Information Model (BIM) specification by 2014, interactive decision support tools may play an even greater role in the planning process. Currently, the next stages of this project aim to address the issues of integrating games-based interactive visualisation methodologies with a more traditional CAD-based approach. This potentially includes the development of an interactive 3D BIM tool aimed at smaller and medium sized civil engineering and architecture firms – who may not always find benefit in making use of all of the stages of the BIM process offered by professional tools such as Autodesk Revit and Bentley Systems Generative Components, especially for less complex projects.

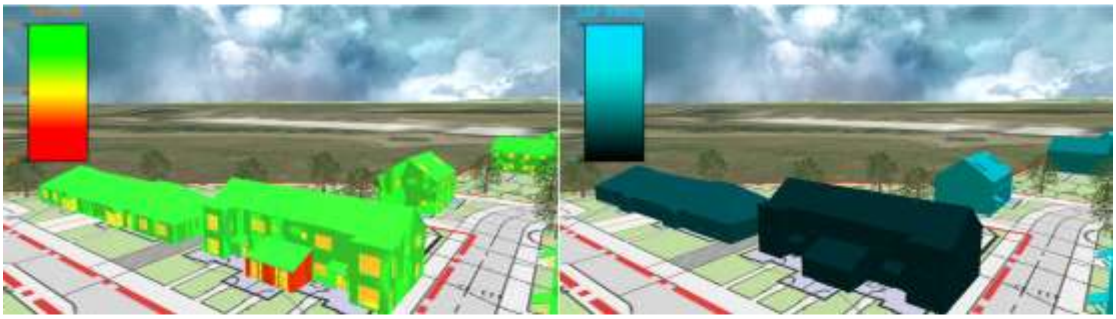

Figure 4: U-value, heat mapping and Standard Assessment Procedure rating visualisation.

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