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IMMERSIVE AND NON IMMERSIVE 3D VIRTUAL CITY: DECISION SUPPORT TOOL FOR URBAN SUSTAINABILITY

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SUMMARY*: Sustainable urban planning decisions must not only consider the physical structure of the urban development but the economic, social and environmental factors. Due to the prolonged times scales of major urban development projects the current and future impacts of any decision made must be fully understood. Many key project decisions are made early in the decision making process with decision makers later seeking agreement for proposals once the key decisions have already been made, leaving many stakeholders, especially the general public, feeling marginalised by the process. Many decision support tools have been developed to aid in the decision making process, however many of these are expert orientated, fail to fully address spatial and temporal issues and do not reflect the interconnectivity of the separate domains and their indicators. This paper outlines a platform that combines computer game techniques, modelling of economic, social and environmental indicators to provide an interface that presents a 3D interactive virtual city with sustainability information overlain. Creating a virtual 3D urban area using the latest video game techniques ensures: real-time rendering of the 3D graphics; exploitation of novel techniques of how complex multivariate data is presented to the user; immersion in the 3D urban development, via first person navigation, exploration and manipulation of the environment with consequences updated in real-time. The use of visualisation techniques begins to remove sustainability assessment's reliance on the existing expert systems which are largely inaccessible to many of the stakeholder groups, especially the general public.*

KEYWORDS*: Visualisation, Virtual Environment, Sustainability, Simulation*

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1. INTRODUCTION

In addressing the complexities of sustainable urban planning it is important to consider the physical structure of the urban development alongside less tangible economic, social and cultural factors (Hamilton 2005). Often major urban development projects extend over prolonged timescales (up to 25 years in the case of major regeneration projects), involve a large number of stakeholders, and necessitate complex decision making. Hunt, Lombardi and Rogers (2008) list five major stages in the development of such projects; Visioning, Feasibility, Design, Construction and Occupancy. Many of the key project decisions are made early in the process, during the Visioning and Feasibility stages. Therefore early stage access to critical information is essential; otherwise decision making is likely to be flawed and may result in compromise and potentially unsustainable development. Immersive and non immersive 3D virtual city representations may be used to aid comprehensive assessment of this critical information and may make holistic decision making easier and more accessible to a range of stakeholders.

The current prevailing practice in urban design is for decision makers to seek agreement for proposals once key decisions have been made. These decisions may include road layouts which are often determined without adequate consideration of the impact of subsurface data on the design of foundations for adjacent buildings or without public consultation on the public acceptability of the building locations. Road layouts also influence the subsequent locations of buried/subsurface infrastructure. Potentially, therefore, by failing to optimize acceptable layouts early on, the longer-term sustainability of developments could be compromised, including the costs and overall delivery time of projects. Whilst there are numerous decision support tools available that may support sustainable decision making for urban developments these have limitations as they:

- Are dominated by the perceptions of the “expert” decision makers (e.g. planners, architects, and design engineers) and focus mainly on the technical design elements of a project;
- Are typically 2-dimensional, when in reality the problems they are required to address are 3-dimensional (volumetric) and 4-dimensional (temporal);
- Lack an effective means of communication to a range of stakeholders, including the general public;
- Do not adequately consider the complex and interconnected domains (environmental, economic, social) that affect the sustainability of our urban areas; and
- Have limited predictive capacity.

Given the increasing strain on our urban areas, what is required is a single decision support framework, which overcomes the limitations above, enabling the all of the stakeholders involved especially the “non-experts” a greater understanding of the complex issues involved in sustainable decision making.

The main theme of this paper outlines a platform that combines computer game techniques and modelling of economic, social and environmental indicators to provide an interface that presents a 3D interactive virtual city with sustainability information overlain. The key component of such a tool is visualisation to aid interaction between stakeholders and to communicate complex datasets. Previously two dimensional visualisation has been used to view and analyse a number of factors in the urban design arena, including transportation (Arampatzis et al. 2004; Fedra 2004) , goods & markets (Semboloni 2007) and crime (Lodha & Verma 2000). However given the complex space that urban planners are trying to optimise, an immersive and non immersive 3D graphical representation of the urban development may be useful for collaborative sustainable urban design as it has been shown that visualisation in three dimensions (3D), using virtual environments, has the ability to engage fully the user’s perceptual and spatial faculties and aid processing of complex information (Pettifer & West 1997). There has been previous work on developing virtual environments to aid decision making in urban (Köninger & Bartel 1998; Chang et al. 2007) and rural arenas (Ball et al. 2007; Miller et al. 2008). However, these tools tend to concentrate on a particular attribute and most make little attempt at presenting the key data to the user, concentrating only on the visual appearance of the environment.

The development of 3D graphics for urban areas has increased over the years due to innovation in the video games industry where research has been applied to procedural city generation (Weber et al. 2009; Kelly & McCabe 2007), which has evolved to avoid bottlenecks in CPU and GPU and aims to render massive dynamic cityscapes and landscapes at interactive frame rates (Mantler & Jeschke 2006). Greater flexibility and control of the GPU is possible with the programmable pipeline using shader programs, which is now standard in most gaming applications and 3D graphical renders (Mantler & Jeschke 2006). Creating a virtual 3D urban area using the latest video game techniques ensures: real-time rendering of the 3D graphics at an interactive frame rate; exploitation of novel techniques of how complex multivariate data (environmental, social and economic data) is presented to the user; immersion in the 3D urban development, via first person navigation, giving the impression of actually being in the environment and exploration and manipulation of the environment with consequences updated in real-time. The underlying indicator models that are presented in the next section are simplifications and the main focus of the paper is presenting how complex sustainability data can be projected onto a 3D physical urban model that could be accessed by non technical experts thus helping them make more informed decisions. The models can easily be refined and updated when better data and models become available. Further, the detail of the sustainability criteria could be amended at a later stage and by different research teams if needs be.

1. METHODS

The tool is split into 3 components: Interface, Engine and Games techniques, and is developed using the XNA programming environment utilising pixel shader language 3 (Figure 1). A bespoke framework was developed to ensure seamless integration and real-time updates of indicator models with the Interface. Furthermore, updates of input parameters, such as building location, type or environmental, social and economic indicators, is required to be in real time for an effective decision making tool (Isaacs et al. 2008). This level of interactivity would not be possible using existing off the shelf software. The framework presented uses visualisation techniques developed by the computer games industry making efficient use of CPU and GPU therefore maximising the amount of computations and data rendered using commodity hardware.

The use of the C# (C sharp) programming language coupled with the XNA and Direct X development libraries, which are designed for games development, allows the application to run on recent consumer computer hardware, as opposed to the high-end, specialised system required to run CAD rendering systems efficiently. The system has also been designed in an object-orientated manner, this not only leads to better resource use but also allows a high degree of control over the separate components of the application.

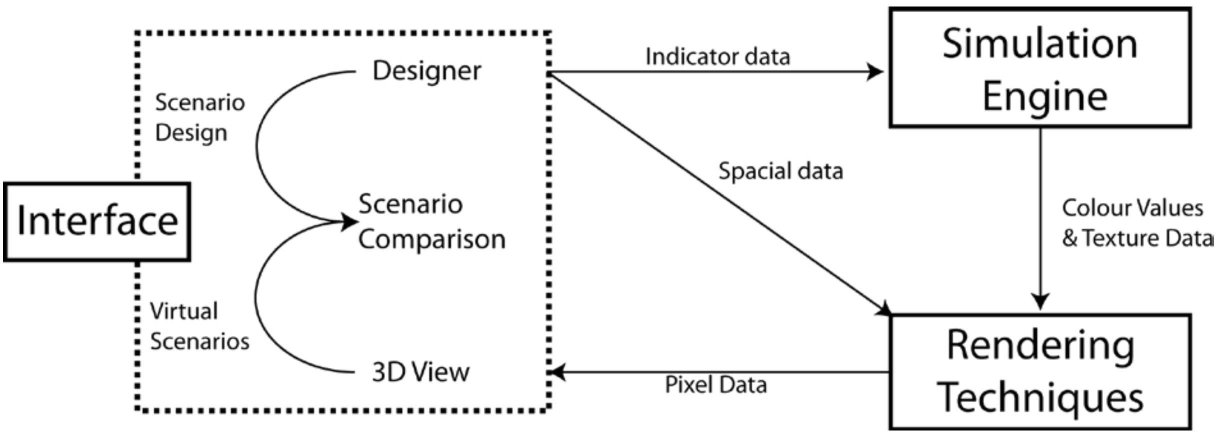

FIG. 1: Overview of framework structure

The prototype also utilises some the large array of developed libraries available for the C# and .Net languages. This includes a library which allows communication with the Nintendo Wii remote (WiiMoteLib) , allowing the navigation of the environment to be controlled via the Wii remote and also an animation library (XNA Animation Component Library) which allows complex animated 3d models to be included in the virtual environment.

2. INTERFACE

The interface comprises 3 parts: Designer view; integration of 3D models and GIS and Scenario comparison. These are described below.

2.1 Interface: Designer View

The designer view is the first stage of the virtual city creation where the masterplan can be created or imported and buildings and components are assigned initial indicator attributes. The tool allows stakeholders to design the physical structure of the environment in a virtual space (Figure 2). In Figure 2 there are roads (black lines) with buildings (red, pink, purple, khaki) a grass recreational area (light green) and a water feature being created from a masterplan. The designer also allows the users to access and amend the properties of the components within the development and will affect the simulation results immediately.

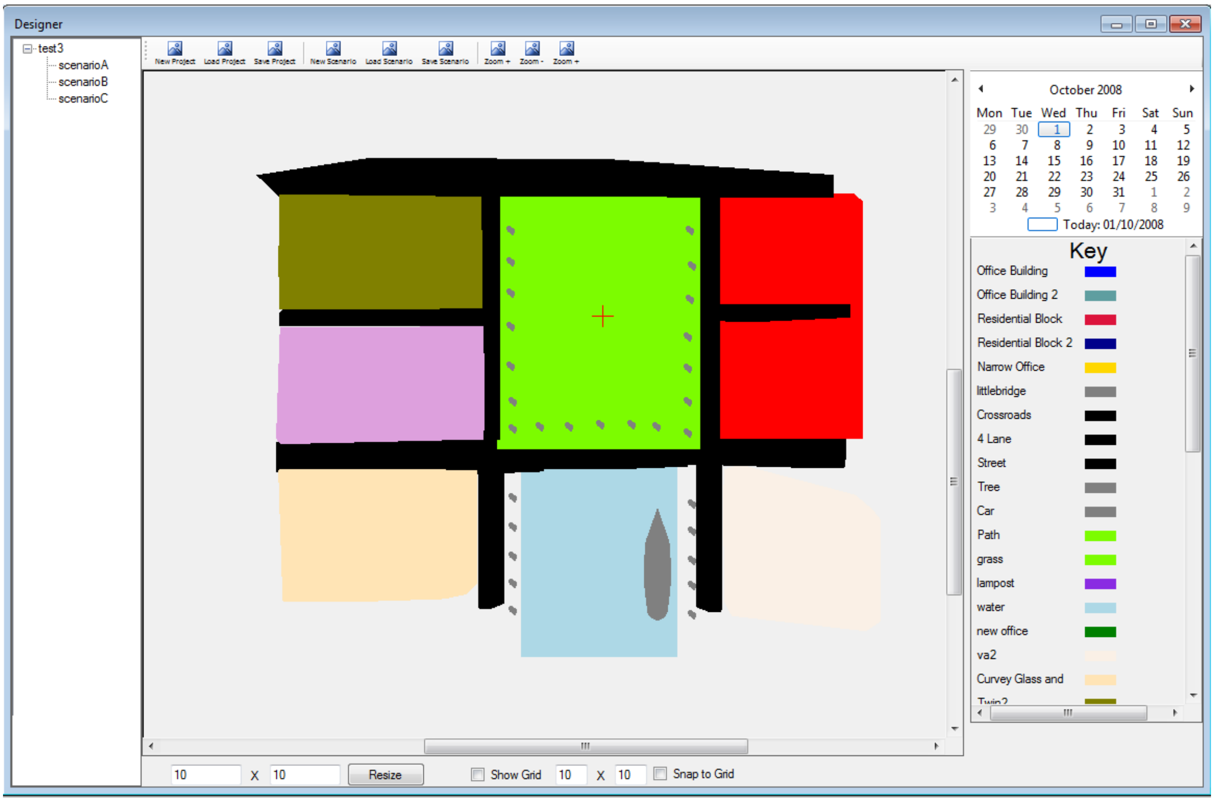

FIG. 2: Design view

2.2 Interface: Integration of GIS and 3D view

Traditionally either 2.5D GIS or full 3D models generated from CAD have been used in city modelling. Existing GIS systems still rely heavily on experts both in the training of the tools and in understanding the forms in which the data is being presented. (Shiffer 1998). Traditional GIS does not provide a realistic physical representation of the city or development being studied. CAD system do enable the creation of 3D models which provide the user with a realistic representation of the buildings and the developments (Al-Kodmany 2002), however CAD systems provide no ability to overlay additional data and provide little context out with the building or area being studied. Here we combine GIS and 3D urban models and embed the 3D models in the surrounding landscape, that is characterised by GIS data, to contextualise the urban area that is undergoing sustainability assessment. The ability to visualise part of the city that is undergoing the development or regeneration within the wider city context is likely to improve engagement with the communication tool and bring a greater level of involvement from all participants in the planning process (Levy 1995)

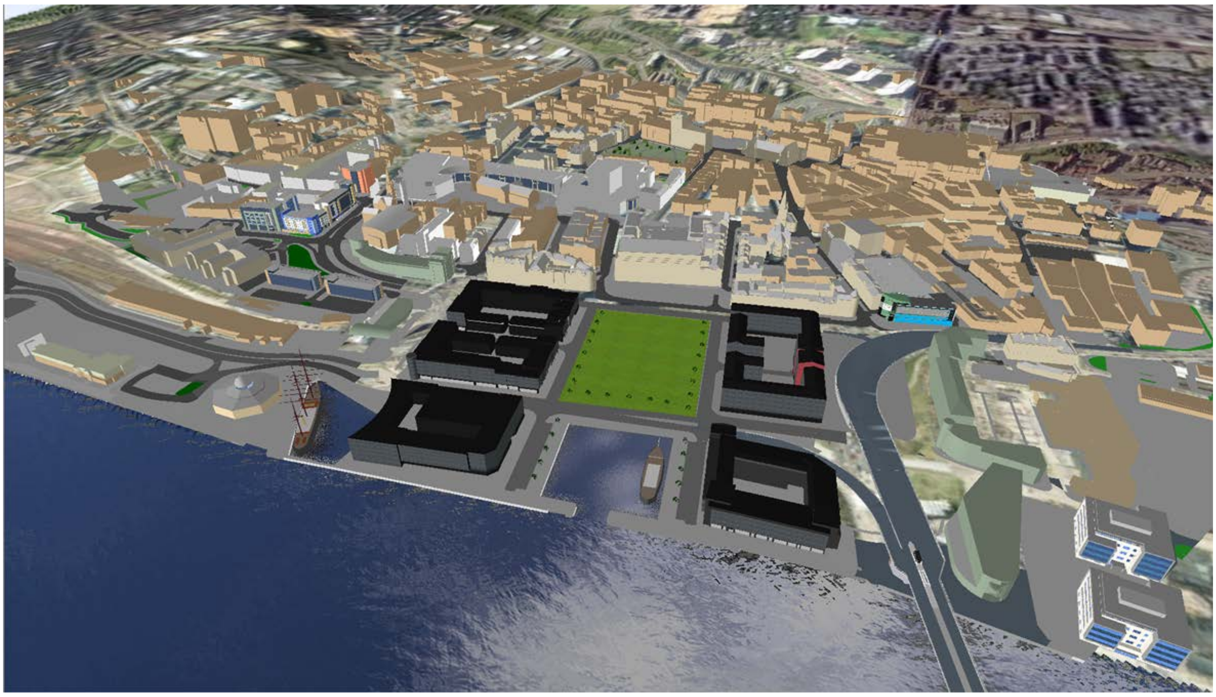

FIG. 3: 3D representation of proposed development within the city-wide context. The textured buildings in the centre of the image are consistent with the buildings created in designer view in Figure 1.

The custom engine allows the user to have interactive control enabling the user to view the proposed development from any conceivable viewpoint. This allows the user to become fully immersed in the proposed development, to a much greater degree than 2D plans, GIS, or rendered 3D stills. The use of 3D environments also enables some of the user's cognitive navigation and visual perception processing to be performed on a sub-conscious level as they will already have developed this ability through real world activities, such as walking through a city, with little conscious thought (Charters et al. 2002).

2.3 Interface: Scenario comparison

The interface provides a spit screen view to facilitate investigation of contrasting planning scenarios such as the effect of building attributes on urban performance (Figure 4). The spilt screen view allows the two scenarios to be run simultaneously enabling the users to stop and compare the scenarios at any time point. The scenarios may be changed at anytime thus allowing the identification of the best scenario from several possibilities.

FIG. 4: Split screen comparison, here the comparison is based on preference of building materials.

3. SIMULATION ENGINE: INDICATOR MODELLING

Six indicators are modelled spatially and temporally in the prototype, two from each of the pillars of sustainability (environmental, economic and social). The indicator values can be determined for each square metre for each building, these are then summed over all buildings to determine an indicator value over time for the specific development as in Figure 5). The models are informed from existing data, for example, energy usage for buildings is determined using the industry standard National Calculation method (BRE 2008) which provides the energy usage of a building based on its attributes, materials and seasonality. Multicriteria Analytic Network Process (ANP) models describe the relationships between the sustainability indicators, and prioritise the indicators, in a transparent manner, as expressed by a specific stakeholder and can provide an overall assessment of sustainability. The indicator models describe the temporal changes of each indicator and are derived from collected data or literature and the ANP methodology will combine the indicator values providing a transparent aggregated sustainability assessment (Isaacs et al. 2010a) although the data can also be presented in a non aggregated form.

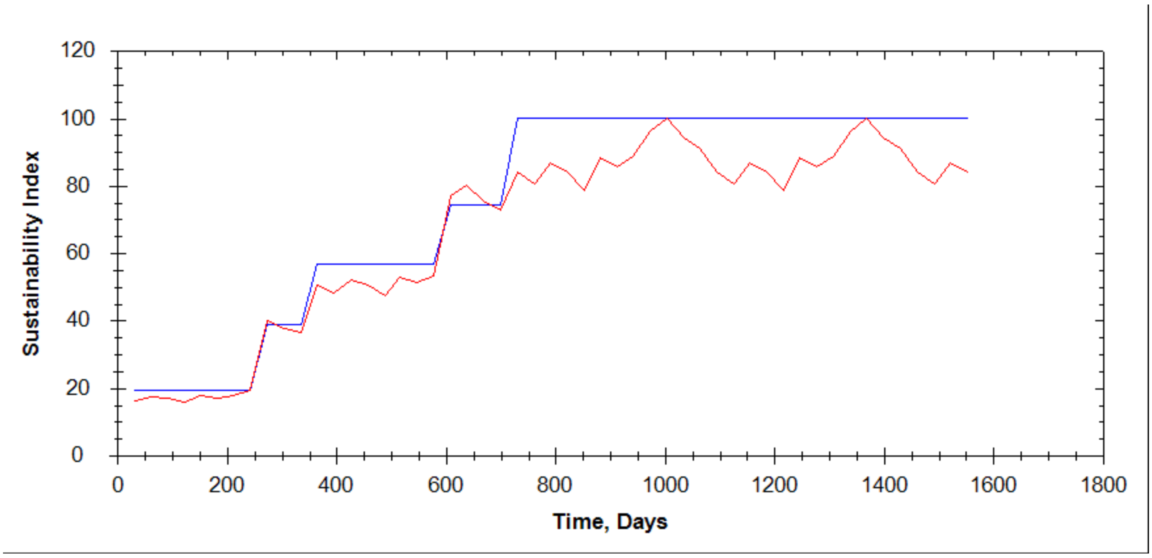

FIG 5.: Plot of economic (blue) and energy use (red) indicators over 5 years.

4. GAMES TECHNIQUES: PROJECTION OF COMPLEX DATA ON 3D INFRASTRUCTURE (VISUALISATION TECHNIQUES)

The overlay of multivariate sustainability information onto the physical models is done using two visualisation techniques. Visualisation techniques provide a means to convey complex sustainability data to the users by mapping the aggregated measure onto a simple colour map (simple blend technique) or by preserving some of the underlying indicator values (weaving) (Hagh-Shenas et al.) as shown in Figures and 7, respectively). Traditional radar diagrams are also used to provide quantitative measures of the indicators for statistical analysis (Isaacs et al. 2010b).

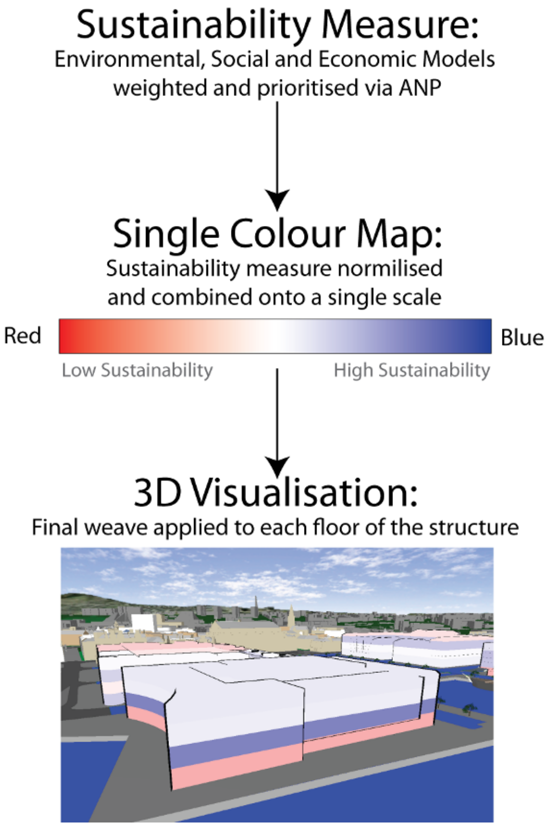

FIG. 6: Blend technique

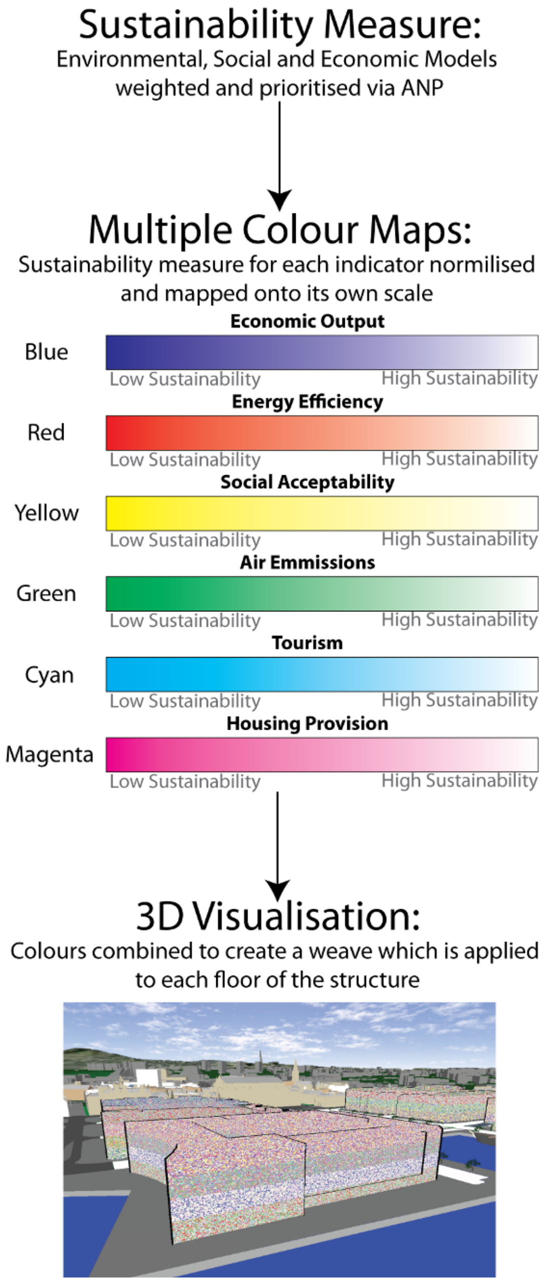

FIG. 7: Weave technique

The visualisation techniques employ pixel and vertex shaders for efficient rendering of data. The pixel shaders control how each pixel of the building mesh is drawn allowing the building textures to be changed quickly on the graphics processing unit (GPU) removing the need to perform computationally intensive texture manipulation on the CPU (Purcell et al. 2002). For the blending technique, once the required colour for each building floor has been generated, a simple texture is created containing a one pixel square for each floor. The pixel shader uses the current pixels position in the building to "look up" the colour, from the generated texture that should be applied (Figure 8).

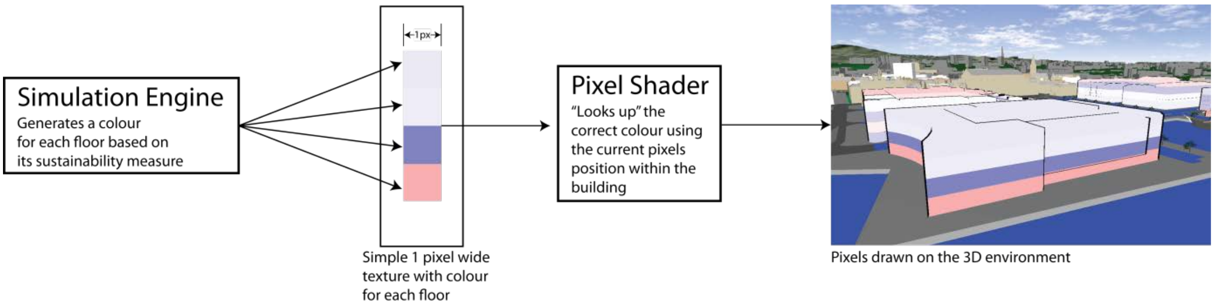

FIG. 8: Steps in blending pixel shader

Similarly, the weaving technique creates a simple texture; however as the separate indicators values must be preserved, this texture contains a strip of colours for each floor. This requires the generated texture size to be equal to the number of indicators by the number of floors in the building; this is still much smaller and quicker to process than the buildings original texture. The weave technique also needs a random noise texture, allowing for the random selection of the indicator colours, to be generated. The noise texture is created as a large texture populated with different alpha channel values, representing each indicator, distributed randomly over the texture. The pixel shader uses the alpha value in the noise texture to select the correct indicator and the current pixels position to select the correct colour for the pixel (Figure 9).

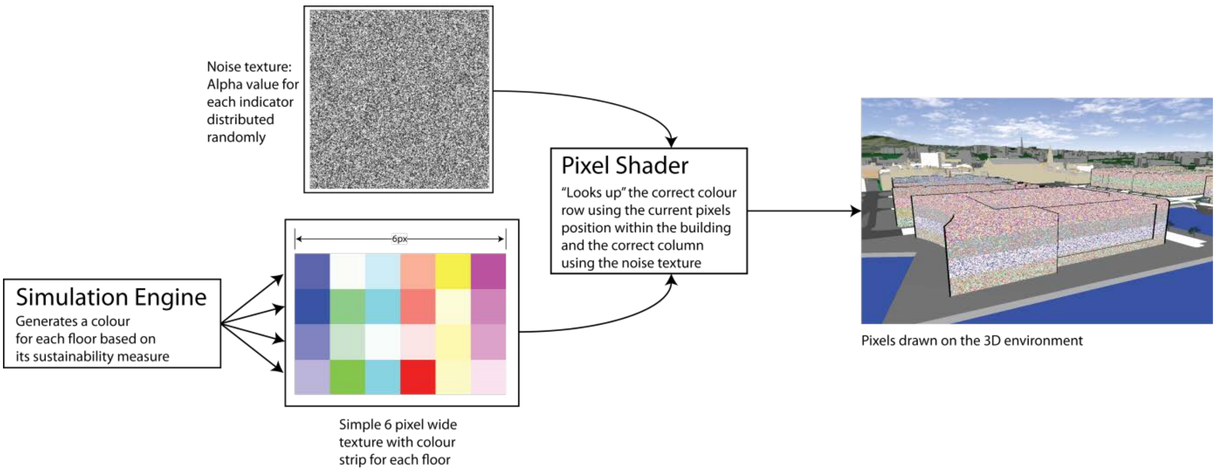

FIG. 9: Steps in weaving pixel shader

5. HIVE ENVIRONMENT

While the application can be used on consumer desktop and laptop machines, it has also been developed to allow its use in both fully immersive and partly-immersive environments. Through the use of a stereoscopic projection environment the user can become fully immersed in the proposed development. The stereo vision allows the user to feel as if they are standing in the environment, as seen in Figure 10, and that the simulation is coming to life around them, isolating them from the real environment (Okeil 2010).

FIG. 10: Application on stereo projection screen (left) and audience viewing (right)

However as the application is designed to be used for sustainability assessment and planning it would not always be possible to have all the stakeholders visit the stereoscopic projection environment. To allow a wider range of users to experience the proposed development in stereovision the application can also utilise a portable 3D monitor. This allows the application to be executed on a laptop connected to the 3D monitor which, like a normal computer display, will not fully immerse the user but will allow the user to better perceive depth and perspective with the aid of stereovision.

6. PILOT TESTING

Pilot testing of the prototype was undertaken to determine if the wide variety of stakeholder groups can obtain and understand the complex information being presented. This requires a simulation of the type of decision making process that the tool will be used in. Sustainability and planning decisions are rarely decided by one person but by groups of stakeholders at various consultation, engagement and decision making meetings, to reflect this a focus group methodology will be used. The use of focus groups will allow a greater insight into how the stakeholder groups arrive at a decision by using the prototype together, than would be possible through the use of solo trials (Morgan 1997). The focus groups used will be comprised of between six and ten members of a single stakeholder group, such as planners, engineers and community groups. This approach will allow the greatest range of opinions without reducing the depth and substance of the discussions (Gilbert 2001), but will also allow the observations, performance and experience of the different types of stakeholders to be compared.

Using three focus groups, pilot tests were performed to investigate the usefulness of the decision making tool to perceive differences in relative sustainability between two hypothetical scenarios. Initially there was a large (80%) difference between the two scenarios, in terms of the sustainability, and this was systematically decreased by intervals of 10% until both scenarios were equal. In order to investigate if the different visualisation techniques effected the minimal discernable difference this process was repeated for both the blend and weave approaches to displaying the data.

The participants were asked to select as group, using both the blend and weave methods, the most sustainable scenario and to give some reason as to why they had made this choice. For both techniques 100% of the participants were able to determine which scenario was the most sustainable and also when the scenarios were equal. Through the use of the weaving technique all participants were able to identify which indicators were the causing the greatest impact. Further testing will be carried out on different stakeholder groups and to determine the lowest non-zero threshold at which differences in sustainability between scenarios can be detected i.e detailed study of the 0%-10% range of sustainability difference. General usability and acceptability tests will also be conducted to determine if the prototype can be effectively used by a group and also if the groups use of the prototype is a positive experience.

7. CONCLUSIONS

The aim of this paper was to present a prototype that can be used in an immersive or non immersive environment to facilitate the collaborative nature of decision making for designing sustainable urban developments. Pilot tests have shown that the virtual environment is an useful medium to communicate the interdependent nature of sustainability indicators and to compare and contrast opposing planning scenarios. A visual sensitivity analysis to show how the relative sustainability changes based on urban design and planning decisions can be undertaken by applying the novel visualization techniques. These techniques involve augmenting the physical structure of the urban development with the less tangible economic, social and environmental indicators and begin to remove sustainability assessment's reliance on the existing expert systems which are largely inaccessible to many of the stakeholder groups, especially the general public. Caution must be taken as the decision making tool is limited by the reliability and quality of the underlying data used in the models, however, the underlying models can be replaced by better models as they become available and the criteria for sustainability assessment can also be refined. Future work, as discussed in the pilot testing section, includes a full usability test to determine which visualisation techniques are preferred by different stakeholder groups.

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