MODELLING AND VISUALIZING SUSTAINABILITY ASSESSMENT IN URBANENVIRONMENTS

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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. Comprehensive assessment of critical information will involve a number of domains, such as social, economic and environmental, and input from a wide a range of stakeholders. This makes rigorous and holistic decision making, with respect to sustainability, exceptionally difficult without access to appropriate decision support tools. Assessing and communicating the key aspects of sustainability and often conflicting information remains a major hurdle to be overcome if sustainable development is to be achieved. We investigate the use of an integrated simulation and visualization engine and will test if it is effective in: 1) presenting a physical representation of the urban environment, 2) modelling sustainability of the urban development using a subset of indicators, here the modelling and the visualization need to be integrated seamlessly in order to achieve real time updates of the sustainability models in the 3D urban representation, 3) conveying the sustainability information to a range of stakeholders making the assessment of sustainability more accessible. In this paper we explore the first two objectives. The prototype interactive simulation and visualization platform (S-City VT) integrates and communicates complex multivariate information to diverse stakeholder groups. This platform uses the latest 3D graphical rendering techniques to generate a realistic urban development and novel visualization techniques to present sustainability data that emerge from the underlying computational model. The underlying computational model consists of two parts: traditional multicriteria evaluation methods and indicator models that represent the temporal changes of indicators. These models are informed from collected data and/or existing literature. The platform is interactive and allows real time movements of buildings and/or material properties and the sustainability assessment is updated immediately. This allows relative comparisons of contrasting planning and urban layouts. Preliminary usability results show that the tool provides a realistic representation of a real development and is effective at conveying the sustainability assessment information to a range of stakeholders. S-City VT is a novel tool for calculating and communicating sustainability assessment. It therefore begins to open up the decision making process to more stakeholders, reducing the reliance on expert decision makers.

Keywords: modelling, simulation, sustainability, virtual environment.

INTRODUCTION

Comprehensive sustainability assessment of urban environments involves a number of domains, such as social, economic and environmental, and input from a wide a range of stakeholders. This makes rigorous and holistic decision making, with respect to

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sustainability, exceptionally difficult without access to appropriate decision support tools. Assessing and communicating the key aspects of sustainability and often conflicting information remains a major hurdle to be overcome if sustainable development is to be achieved. Sustainable decision support tools have been developed (Ashley *et al.* 2004) but the authors have concluded that a major barrier to the development and implementation of tools to support urban design is the complexity of the environment in which decision are made (Hull and Tricker, 2005; Bouchart, Blackwood, and Jowitt, 2002). It has also been shown (Isaacs *et al.* 2007) that these tools lack the ability to engage all the stakeholders due to their focus on "expert" decision makers (e.g. planners, architects, and design engineers). A prototype interactive simulation and visualization platform (S-City VT) aims to integrate and communicate complex multivariate information to diverse stakeholder groups with the aim of making better informed sustainability decisions.

METHODS

A schematic representation of the platform is described in Fig 1 and is made up of indicator modelling, multicriteria opinion analysis and 3D visualization which will subsequently be described.

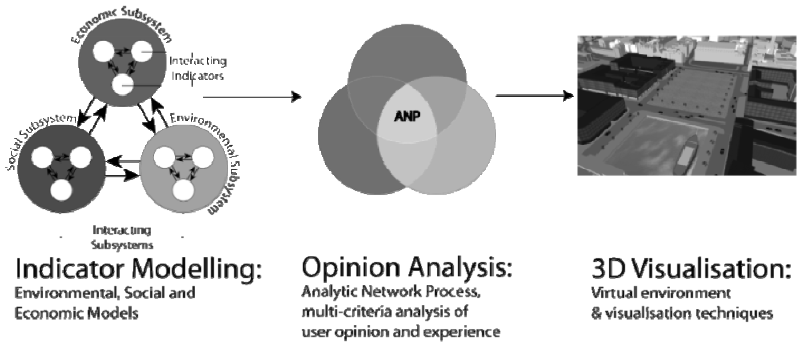


Figure 1: S-City VT methodology.

INDICATOR MODELLING

The indicator modelling defines how each of the indicators vary over space and time. The S-City VT application is built using a modular framework providing flexibility and allowing indicator models to be changed. For the prototype application six sustainability indicators (acceptance, housing provision, energy efficiency, noise pollution, employment and economic benefit) were chosen from a list of indicators identified by preliminary work that will be used to benchmark the sustainability of the case study development (Gilmour *et al.* 2007) this will allow for the models to be validated during the lifetime of the development. The specific six indicators chosen to be modelled provide a spread across the sustainability domains (economy, society and environment) and were identified as having readily available data at the beginning of the case study. The prototype models are described below:

Energy Efficiency

The energy efficiency model is based on the Nation Calculation Method (NCM) which is the industry standard allowing energy efficiency of buildings to be determined (BRE 2009). The NCM method takes into account a wide range of factors, including number of doorways, windows glazing type, exterior construction, and number of floors etc. to produce a metric describing the energy efficiency the building. A NCM report was developed using the NCM tool, representing the typical buildings in the development for a number of different options including external appearance and different mixes of building use.

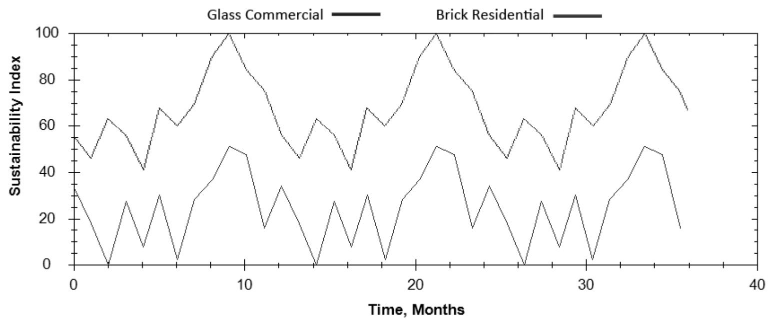


Figure 2: Graph showing temporal changes in sustainability index due monthly energy fluctuations.

This data is input to the energy efficiency model and attenuated with the temporal energy consumption data (DECC 2009) which reflects how the energy use of the buildings change depending on the time of year. (Figure 2) shows how the sustainability index changes as a function of time for two different building types with different functional use (glass, commercial and brick, residential).

Noise Pollution

The noise model calculates the levels of traffic noise arriving at each building and can also calculate the proportion of people that will find certain levels of noise a nuisance. Data about the projected traffic flows for the waterfront development were sourced from Dundee city councils Dundee Waterfront Traffic and Signalling Report (White Young Green 2007). For each road in the proposed development a noise level is calculated using its projected hourly traffic flow. Using a function provided in CRT (1988), (equation 1) this traffic flow can be transformed into a noise level which corresponds to how loud, in decibels (dB(A)), the traffic noise is if the listener were standing approximately 10 metres away from the road side.

$$\textit{Basic hourly noise level } L_{10} = 42.2 + 10\log_{10} q \, dB(A) \qquad \text{equation 1}$$

A noise level associated at each building based on the traffic volume is calculated based on the shortest distance (d) between the noise source (road) and the building using Euclidean geometry. The sound level emanating from each road is obtained by correcting the basic noise level using equation 2. The equation also includes the height (h) of the listener which is constant in these calculations. (CRTN 1988)

$$\textit{Noise Level Correction} = -10 \log_{10}(d'/13.5) \; dB(A) \qquad \text{equation2}$$

$$\textit{where } d' = \textit{shortest slant disatnce from the road } [(d + 3.5)^2 + h^2]^{\frac{1}{2}}$$

To determine the total noise level received by the building the corrected noise from each road must be summed over n roads in the development (equation 3)

$$\textit{Total noise level} = 10 \log_{10}[\textstyle\sum_1^n Antilog_{10}(L_n/10)] \; dB(A) \qquad \text{equation 3}$$

Each building will now have a noise level value representing the total level of noise associated with that buildings location in relation to the roads and their projected traffic flows. Our sustainability measure is achieved by normalizing the noise level (0-100 scale as before) and applying a non linear function (equation 4 (Highways

Agency 1994)), this calculates the percentage of people that will be bothered by a specific level of noise.

$$\%\ \boldsymbol{Bothered} = \frac{\mathbf{100}}{(\mathbf{1}+\boldsymbol{e}^{-\boldsymbol{\omega}})} \quad \boldsymbol{where}\ \boldsymbol{\omega} = \mathbf{0.12}\ (\boldsymbol{L}\ \boldsymbol{dB}(\boldsymbol{A})) - \mathbf{9.08} \qquad \textit{equation 4}$$

Economic Benefit

The economic model utilizes a discounted cash flow calculation to determine the worth of a buildings current cash flow for a specific point in time. The calculation uses a discount rate which allows the cash flows to be discounted back to their present worth.

$$\boldsymbol{Net\ Present\ Value} = \boldsymbol{CF_0} + \frac{\boldsymbol{CF_1}}{(\mathbf{1}+\boldsymbol{r_1})} + \frac{\boldsymbol{CF_2}}{(\mathbf{1}+\boldsymbol{r_2})^{\mathbf{2}}} + \cdots + \frac{\boldsymbol{CF_t}}{(\mathbf{1}+\boldsymbol{r_t})^{\boldsymbol{t}}} \qquad \textit{equation 5}$$

Where CF = cash flow for that year. r = discount rate for that year. t = the year.

In the equation the capital cost for the construction of the first building is represented by CF0. Capital costs of subsequent buildings will be discounted to this point time. For example the capital cost of a building built two years after the initial building would be discounted using $\frac{CF_2}{(1+r_2)^2}$.

Each building in the simulation has a site preparation and construction phase, during this time the cash flow in for that period is taken as 0 as the building would not yet be sold or rented. The simulation is able to reflect the differences between cash flows for rented and sold buildings. Buildings which are sold will take a large income at the point of sale. As the building has been sold further cash flows for this building will be 0. The discount factor will also apply to the sale income so for two buildings of equivalent value, a building sold in year one will have a higher present value than building sold in year 10. As the building has been sold the upkeep and maintenance of the building will be borne by the buyer and so it not modelled here. Buildings which are rented will take a smaller income every year. Rented buildings may have a rent free period, to encourage tenants, and will have a lay period between leases, during these times the cash flow for that period will be zero. A discount factor is applied to the yearly income to determine its present value, again based on the construction year of the first building.

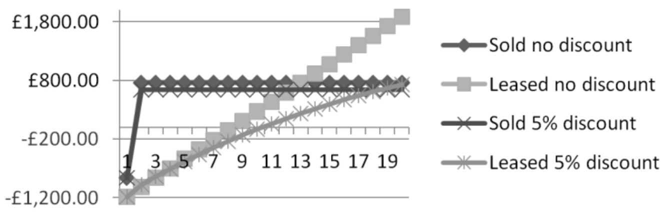


Figure 3: PV for a single building, built in year 0, showing differences between leased and sold income with different discount rates.

The initial cost of the buildings are calculated using the building type (e.g. residential, commercial, retail, social) and the cost per square metre for that type of building. The income from sale or rent is likewise calculated using the projected income for that type of building. These values were sourced from the SET economic report on the waterfront development (Buchanan 2006). The maximum and minimum values are then mapped onto 0-100 and linearly interpolated.

Acceptance
Acceptance corresponds to the acceptance of possible building uses within the development. The masterplan for Dundee has been developed and it was possible through discussion with Dundee council to determine the possible building uses which are under review and included commercial office space, retail units, cafe/bar/restaurant and residential space. The building use survey used a ranking system where the participant was asked to rank possible building uses in order of preference. If the participant had no preference between the building uses at each rank the proportions chosen at each rank would be equal. To determine if this is the case Friedman test was performed using SPSS on the mean rank of each building use, with the null hypothesis being that the mean ranks will be equal.

Ranks

	Mean Rank
Commercial	3.37
Retail	2.51
Leisure	1.54
Residential	2.58

Test Statistics a

Sample Size	106
Chi-Square	107.264
df	3
Significance.	.000

a. Friedman Test

The results of the Friedman test show that there is a significant difference ($p<0.001$) between how the users ranked the different building uses. Combined with post-hoc analysis of the results it is possible to model the acceptability building uses in the following order: Leisure (highest ranked), Retail and Residential (equal ranked) and Commercial (Lowest Ranked). To create a sustainability index for the acceptability of each building these rankings are mapped onto a 0-100 scale, with Leisure at 100 (highest sustainability), Retail and Residential at 50 and Commercial (lowest sustainability) at 0.

Housing Provision and Employment
At the current stage of development the Housing provision and Employment models are much simpler. The Housing provision model calculates the percentage of the building designated as residential space this provides a sustainability index of 0-100 which will be comparable with the other models. The Employment model using existing information regarding different building uses (e.g. commercial, leisure etc. and building sizes to provide the likely number of jobs a specific building might create or sustain. The maximum and minimum values are then mapped onto 0-100 and linearly interpolated.

MULTICRITERIA OPINION ANALYSIS

One of the problems with traditional sustainability assessment is involving the views and experiences of a wide range of stakeholders (Isaacs *et al.* 2010a). Many of the traditional methods of aggregating indicator values, such as Multi Attribute Utility Theory (MAUT), lack transparency leaving the users in a position where they do not fully understand how the resulting weightings have been derived (Dodgson *et al.* 2009; Paracchini *et al.* 2008).

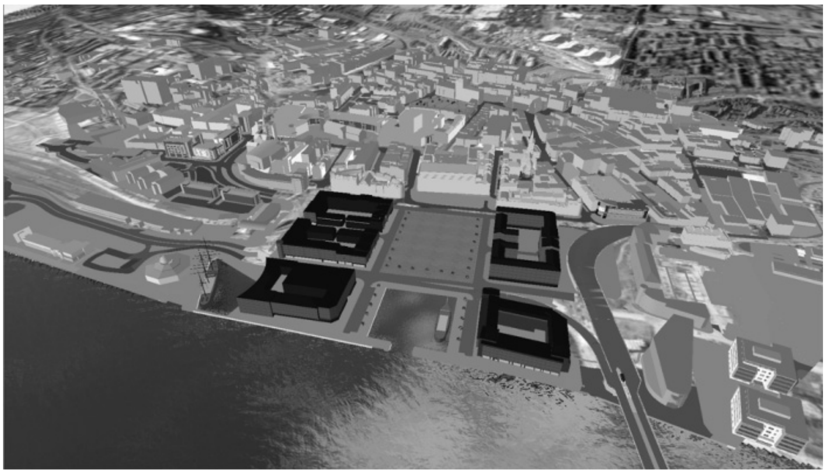
The Analytical Network Process (ANP) method uses interactive network structures which give a more holistic representation of the overall problem(Saaty 2006). Components of the problem are connected, as appropriate, in pairs with directed lines simulating the influence of one component over another. The components in a network may also be regarded as elements that interact and influence each other in regard to a specific attribute. (Saaty 2006).. ANP allows cross-cluster interactions as well as inter-relationships between elements. It is structured naturally and allows for a more realistic representation of the problem, but its main strength lies in providing the user with the ability to include their own personal knowledge and opinions about an interaction through the use of pair-wise comparisons (Saaty 2006; Bottero *et al.* 2007).

The prototype application provides the user with an interface that allows them to apply the ANP method to the indicators being modelled, thus defining the network that connects them. The prioritized list of elements which are derived from the ANP analysis are used in the 3D visualization to provide a weighting to the indicators being visualized. For example in the blend method the weightings are used to determine how much of an individual indicators colour scale contributes to the final single indicator when the colours are combined.

3D VISUALIZATION

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 characterized by GIS data, to contextualize the urban area that is undergoing sustainability assessment. The ability to visualize 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)

Figure 4: 3D representation of proposed development within the city-wide context.



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). As has already been shown (Isaacs *et al.* 2010b) S-City VT provides the user with a viable representation of the actual development. However S-City VT does not only provide the user with a physical representation of the development, through the use of the latest rendering techniques it also allows the user to view the multivariate sustainability data produced by the underlying mathematical models.

Blending

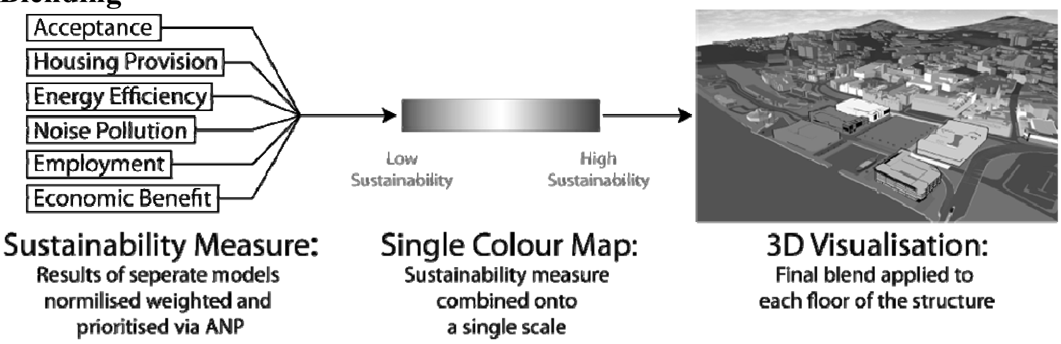


Figure 5: Overview of the indicator blending technique

The blending technique, as shown in figure 5, simply takes the all the sustainability measures for each indicator, calculated by the sub system and ANP models, combines them into a single value. This valued is then mapped to a single colour scale. The colour scale used can be selected from a number of colour scales known for their discriminating abilities (Levkowitz and Herman 1992) these include the heated object, magenta, local optimized, and spectral. Using the hot-cold scale demonstrated in figure 5 a building or floor with high relative sustainability would appear blue while a building with low sustainability would appear red. This method gives a single indicator of sustainability and provides the easiest way of comparing the relative sustainability of different options or scenarios.

Weaving

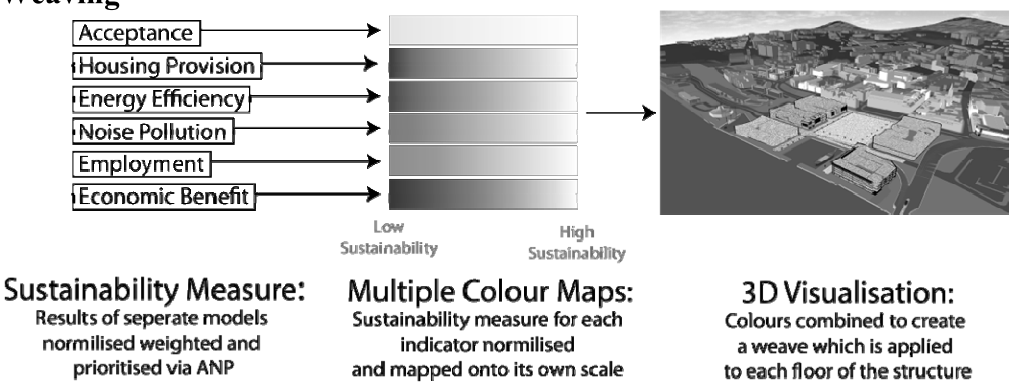


Figure 6: Overview of the indicator weaving technique

Whilst the blending technique, combines the indicator values, the weaving technique (figure 6) attempts to preserve some of the underlying information so that the user can still identify which indicators or cluster are causing the greatest effect (negative or positive) on the sustainability of the building. The colour weaving technique (Hagh-Shenas *et al.* 2007) uses a different colour scale for each indicator (figure 6) to attempt to preserve this information. The colours from each scale are then randomly weaved into a patchwork like texture which is applied to each floor of the building. The size of the squares or patches in the weave can also be changed depending on the user's preferences. A small patch size will give an overall representation of the sustainability, with darker shades representing low sustainability and lighter shades representing higher sustainability. A larger patch size will allow user to identify quickly which colours stand out the most, and therefore which indicators are having the greatest impact.

Traditional Graphical Techniques

Radar graphs, figure 7, allow the stakeholder to compare the sustainability of different buildings based on the indicator values. The shape, size, colour and point values will be different for each building allowing a detailed comparison.

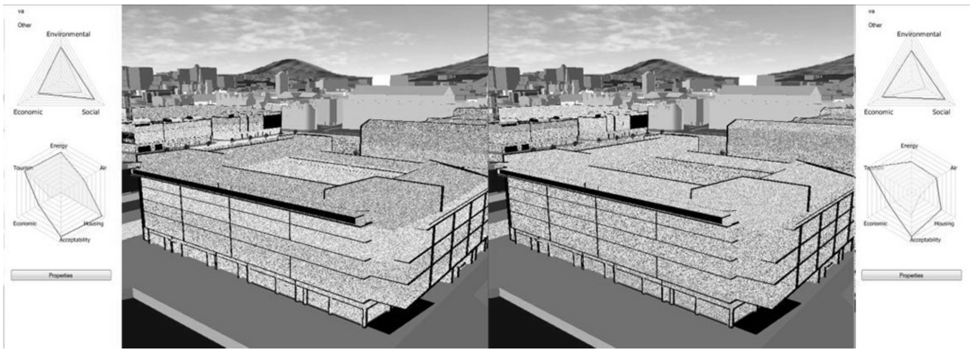


Figure 7: Comparison of scenarios using traditional radar graphs and colour weaving.

Parallel coordinates allow the user to compare all indicator values for all the buildings in a scenario (figure 8). Buildings can be selected and their trace in the graph is highlighted. The colours in the graph correspond to those in the blending technique.

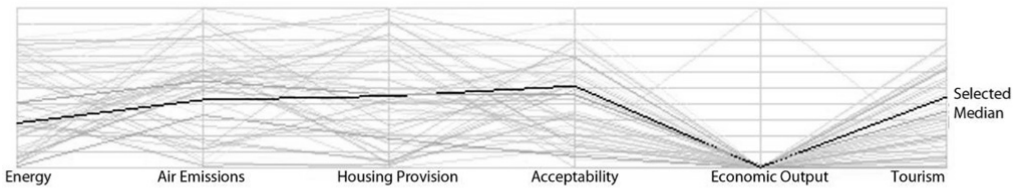


Figure 8: Parallel coordinate graph for sample development.

Simple temporal graphs plot the all the indicator values over the life time of the development. These allow the user to identify the interconnectivity of the indicators and to identify where and why sudden changes occur (figure 9).

Split screen comparison

While the methods detailed allow the sustainability of a building or development to be determined, they do not in themselves allow the user to compare alternate courses of action. A split screen rendering approach has been adopted which allows the user, using any of the techniques, to compare two scenarios side by side throughout the life cycle of the development.

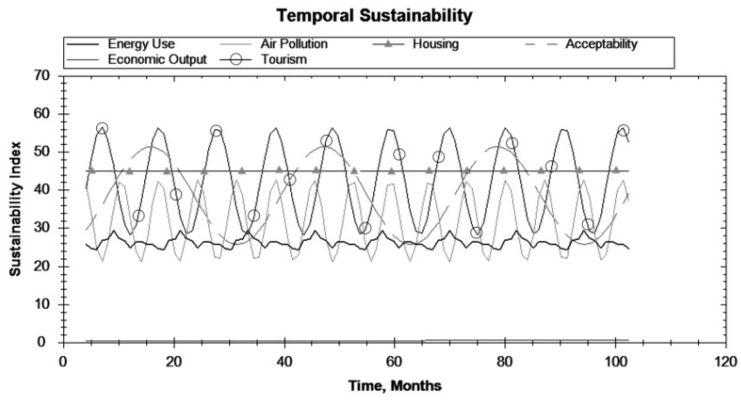


Figure 9: Indicator graph showing changes in 6 indicators over time.

CONCLUSIONS

As our urban centres continue to grow and new or regenerated urban centres are developed the need for greater stakeholder involvement in the decisions being made will also be required. Decision support tools will have a much greater role to play in ensuring that this stakeholder involvement is realized, and it is important that these tools allow and encourage this involvement. We present how traditional multivariate methods can be combined with complex multivariate information and presented on a virtual urban development. We show how the sustainability data can be presented differently using state of art techniques in visualization stemming from the computer games industry. Preliminary testing of the decision support tool was promising with all groups detecting a large difference in sustainability of contrasting scenarios. Future work will include a large scale usability test to address if the prototype is appealing (look and feel), useable (navigation, options etc. and effective. The study will also investigate which visualization method was most easily understood and by whom and at what point can differences in scenarios no longer be distinguished. Through the use of virtual environments and visualization, S-City VT begins to open up the decision making process to more stakeholders, reducing the reliance on expert decision makers. It allows all stakeholders to not only envisage the development in a much more realistic setting than current methods allows, but also to immediately envisage the consequences of any decisions being made both now and in the future.

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