1 Abstract

Sustainable decision making in Urban Design is a complex and non-linear process that requires the interaction of a wide variety of stakeholders. The engagement of a range of stakeholders throughout the decision making process presents challenges including the need to communicate the complex and interdependent facets of sustainability and the need to demonstrate the short and long term implications of alternative courses of action.

This paper presents the results of an initial application of a prototype simulation and visualisation tool (S-City VT) that was developed to enable all stakeholders, regardless of background or experience, to understand, interact with and influence decisions made on the sustainability of urban design. S-City VT takes the unique approach of combining computer game technology with computer modelling to present stakeholders with an interactive virtual development. The paper uses the Dundee Central Waterfront Development Project as a case study to evaluate the potential for the application of the tool and explains how parallel research work on the implementation of a sustainability enhancement framework for the Central Waterfront Development has informed the choice of sustainability indictors and identified the key stakeholders in the decision making processes.

The paper shows how stakeholders can be presented with the outputs from the model using a 3D visualisation of the development and thus enables judgements to be made on the relative sustainability of aspects of the development. The visualisation tool employs a number of different methods of displaying the sustainability results to the stakeholders. These methods can show data in varying levels of complexity, depending on the expertise of the stakeholder, empowering all stakeholders by illustrating possible interactions between indicator values and sustainability and by showing how different stakeholder perceptions of the importance of the indicators can influence the sustainability assessment.

Initial tests on the effectiveness of the different visualisation methods in displaying the model output to communicate the sustainability of the Development are described. The results of the tests and presented and discussed and conclusions are drawn on the further development and application of the tool to model and visualise through time the possible results of decisions made at different stages of the project.

2 Introduction

Sustainable development is a vision of progress, which integrates immediate and long term needs, local and global needs, and regards society, environment and economics as inseparable and interdependent. However for many, sustainable development is often seen as a complex issue that is not definable in practical terms. Although a large body of work has been undertaken to conceptualise sustainable development and there is a growing awareness of it, the real challenge is putting a holistic and integrated view of sustainability into practice. An integrated view involves the full consideration of all aspects of sustainability (society, environment and economics).

Sustainable decision making in urban design is a complex and non-linear (iterative) process which requires the interaction of wide variety of stakeholders. Effective decision making is dependent on genuine stakeholder contribution during the decision making process, but the current prevailing practice is for decision makers to seek agreement for proposals once the key decisions have been made (Geldof, 2005). Tools to support the decision process are commonplace but are dominated by the perceptions of the “expert” decision makers (e.g. planners, architects, and design engineers) and focus mainly on the technical design and optioneering stages of the process. Sustainable decision support tools have been developed (Ashley et al, 2004) but the applicants 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 (Bouchart, Blackwood & Jowitt, 2002; Hull & Tricker 2005). In particular, engagement with the general public throughout the decision making process presents challenges in communicating not only the complex and interdependent facets of sustainability in decisions, but also in providing an understanding to stakeholders of the short and long term implications of alternative courses of action.

It is therefore believed that there is a need for new decision support tools that can deal with the complexity of urban design and which go beyond the technical orientation of previous tools (Sahota & Jeffery, 2005) to enable the real inclusion of sustainability in the decision-making processes. The key component of such tools is visualisation to aid interaction between stakeholders. Visualisation has been used to visualise and analyse changes in the urban design arena (Shellito et al. 2004; Semboloni et al 2004) and to model the best options for sustainable transport systems (Kurt, 2004). However, none have been used to communicate to and integrate the various stakeholders to improve sustainable decision-making and stakeholder interaction.

This paper describes a prototype interactive simulation and visualisation platform (SCity-VT) that integrates and communicates complex multidisciplinary information to diverse stakeholder groups, including local authorities and the general public, to enable them to discharge their duties in a way that contributes to the achievement of sustainable development. This platform uses Computer Games technology, for 3D visualization and rendering techniques to generate a realistic urban development, in conjunction with an underlying computational model (Isaacs et al 2008).

The underlying computational model consists of two parts:

Multi-criteria evaluation methods to support urban development decision-making and determine the effect of varying indicators on sustainability. Using the same indicators the tool will highlight the differences in stakeholder view on priorities of the social, environmental and economic aspects on sustainability. There is no alignment of views as the stakeholders views are often in conflict and therefore there is never a single correct quantitative sustainability measure. The results of the multi-criteria evaluation (Analytical Network Process (ANP)) orders the indicators in terms of their importance i.e. priority.

Sub system models representing the temporal changes in each indicator. These models are based on existing models, such as the SAP (standard assessment procedure) energy model, or derived from data either collected for the project or sourced from urban databases such as Eurostat. (Eurostat, 2008)

The results of the models are shown to the stakeholder in a novel way using a 3D visualisation tool. The stakeholder will be presented with a 3D visualisation of the development that encapsulates the results of the models and thus the relative sustainability of the development. The visualisation tool employs a number of different methods of displaying the sustainability results to the stakeholders. These methods show data in varying levels of complexity, depending on the expertise of the stakeholder, empowering all stakeholders by illustrating possible trade-offs between indicator values and sustainability. Further the tool will model and visualise through time the possible results of decisions made at different stages, affecting the indicator values, during the development using an animated simulation allowing comparisons to be made.

3 Sustainability Inclusion in the Decision Making Process – Dundee Central Waterfront Development Project.

The development work on the tool forms part of a larger research programme, in conjunction with Dundee City Council, to develop a sustainability enhancement framework for the Dundee Central Waterfront project. The elements of this project are shown in Figure 1.

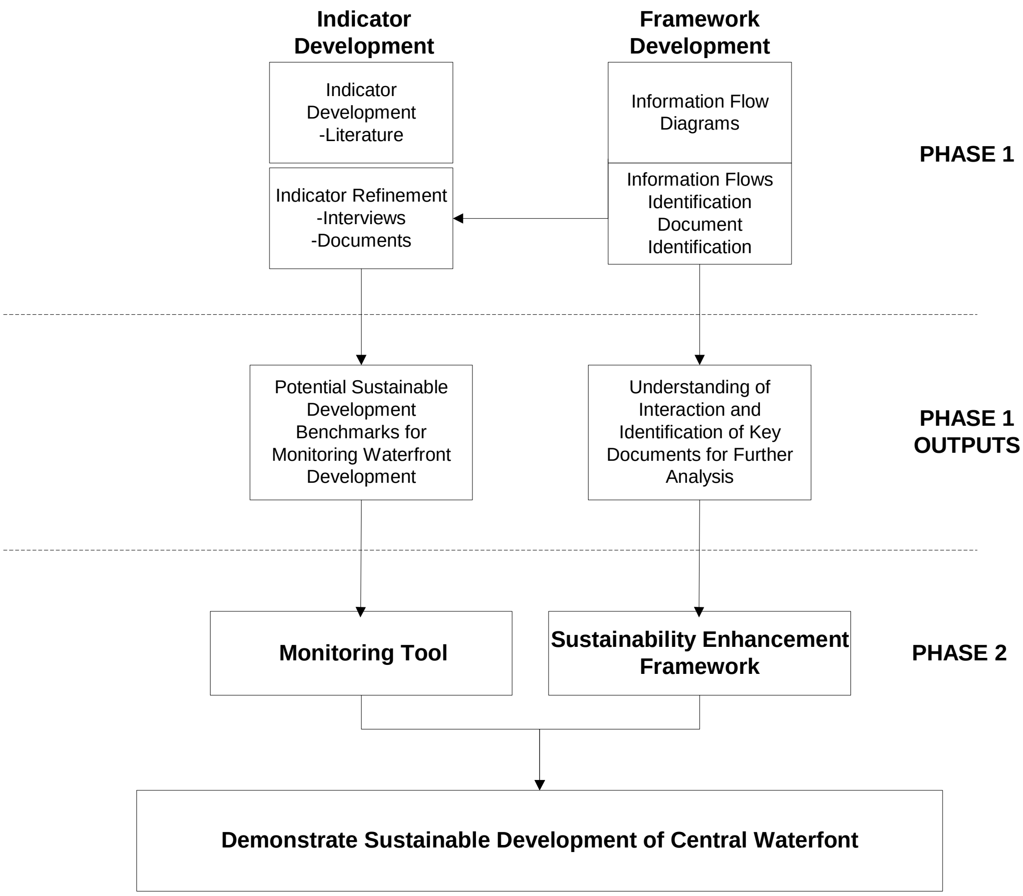

Figure 1 - Dundee Central Waterfront sustainability enhancement study

The enhancement framework will influence decisions taken at various stages of the project's development through the use of indicators that were established to monitor the sustainable development of the Waterfront project. The enhancement framework will combine several activities, each designed to contribute to the overall sustainable development of the waterfront project. Figure 2 outlines how sustainability can be considered at different stages of project life cycle.

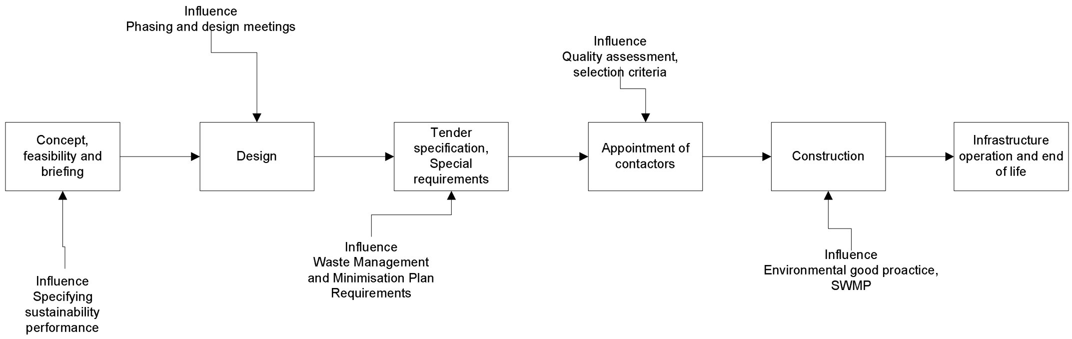

Figure 2. Points of Influence Through the Project Lifecycle

Influencing sustainability at each stage is achieved by embedding sustainable development concepts within the existing decision making and project management procedures and process, e.g. sustainable issues in risk register, special requirement for Site Waste Management Plans in tender documents

Information flow mapping was undertaken at the beginning of the study (Gilmour et al, 2007) to identify key stakeholders, their role in process and the procedures used during decision making. Following this researchers were embedded within the organisation to further identify where sustainability could be influenced in the process and to allow an assessment of the information needs of the stakeholders.

Indicators were developed to provide a benchmark for identifying, reporting and communicating the sustainable development of Dundee Central Waterfront. These indicators help to break down the sustainable development concept to give it a clearer definition and hence make it more comprehensible. Simply put, an indicator is something that helps us understand where we are, which way we are going and how far we are from where we want to be (Simon, 2003). The process of indicator development is an iterative one. The process consists of three main activities, literature review, interviews and document analysis. Each policy document and waterfront specific document that might contain potential sustainability indicators was reviewed and the relevant indicators shortlisted. Each indicator on the shortlist was reviewed to identify its appropriateness to the Central Waterfront, in relation to its scale, geographical area, unit of measurement, focus and direction. Indicators were then grouped into three categories, Economic, Environmental and Social. A definition for each indicator was then assigned together with draft units. The indicators were designed to align as closely as possible with Scottish Government indicators to provide a basis for tangible reporting to the Scottish Government, whilst providing clear and easily understood indicators for internal monitoring at the strategic level.

Where Scottish Government and UK Government indicators did not exist, specific indicators were developed. These were based on the authors' experience of sustainable indicator development (Smith et al., 2002, Butler et al., 2003) and on a range relevant sustainable urban development research papers. Unfortunately, most of the papers presented a conceptual understanding of the urban environment and identified key components of sustainability (McAllister 2005) rather than presenting indicators. However, these key components were developed into indicators, which balanced economic, environmental and social aspects of sustainable development. Well chosen indicators should focus on materiality and accessibility (Olsen. L., 2004) - materiality concerns the information stakeholder want and accessibility refers to ability of stakeholders to acquire and understand the information contained in indicators. Indicators should also have the following four characteristics (Foxon et al., 2002):

Comprehensiveness: The indicators should cover the three categories of economic, environmental, and social in order to ensure that account is being taken of progress towards sustainable development objectives. The indicators chosen need to have the ability to demonstrate movement towards or away from sustainable development according to these objectives.

- Tractability: Sufficient reliable numerical or qualitative data should be available to enable the estimation of spatial and temporal trends.
- Transparency: The indicators should be chosen in a transparent way so as to help stakeholders to identify why indicators are being considered.
- Practicability: The indicators must be practical in terms of time and resources available for any analysis and assessment.

The benchmark indicators were categorised into two groups based on the geographical scope of the indicator; either Waterfront specific or city/region wide. Waterfront specific indicators data are focussed on the development area, whereas city/region wide indicators data are based on the impact of the Waterfront Development at a city/region scale. An example of the latter type of indicator is Retention of Skills Base, where an attribution of the change due to Central Waterfront will be required. One of three forms of baseline data exists for each indicator:

- An initial baseline value for 2007, e.g. population 142,170,
- A value of 0 as a datum for 2007, e.g. Number of jobs created since 2007,
- N/A (not available) where the indicator is not measurable at this time, e.g. Per capita water consumption of new buildings as the area has not yet been developed.

The indicators will have different responsiveness to changes in the development. For some indicators there will be a change in the indicator only at infrastructure stage or the plot development stage, whereas some indicators will change at some or all of the development stages. For example, an indicator such as Air Quality will be influenced at each stage of the development but Retention of Skills Base, which monitors graduate retention rate, will only be influenced at the plot development stage.

A subset of six indicators, two social two economic and two environmental, were selected for modelling and visualisation in S-City VT.

4 ANP method

A stakeholder/analyst defines the indicator network by identifying interrelationships and dependencies amongst the indicators. This is achieved by making judgements of relative importance of each indicator of the model i.e. pairwise comparisons.

Table 1. The Fundamental Scale (From Saaty, 1990)

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate Importance	Experience and judgment slightly favour one activity over another
5	Strong Importance	Experience and judgment strongly favour one activity over another
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance is demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	For compromise between the values	Sometimes one needs to interpolate a compromise judgement numerically because there is no good word to describe it
Reciprocals of above	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	A comparison mandated by choosing the smaller element as the unit to estimate the larger one as a multiple of that unit.
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix
1.1-1.9	For tied activities	When elements are close and nearly indistinguishable; moderate is 1.3 and extreme is 1.9

To illustrate the process, pairwise comparisons of the top-level indicator network is given below. Here we can see that this stakeholder rates economic factors 25 times more important than environmental for the social indicator.

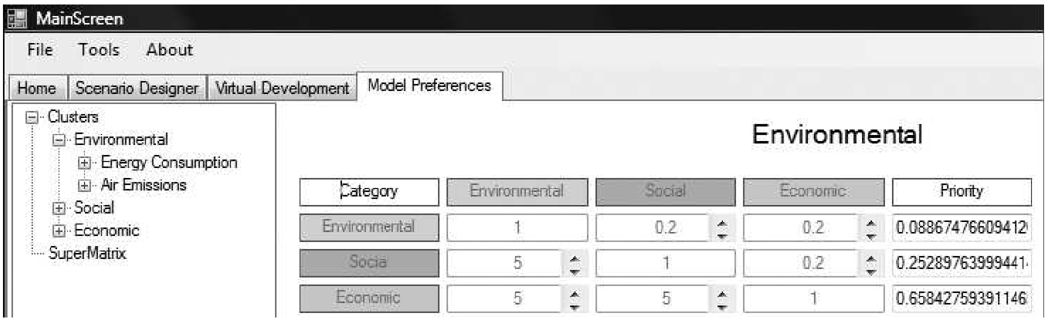

Figure 3. SCity-VT Dialogue for setting ANP parameters i.e. defining the network

When a comparison matrix has been created the elements must be prioritised, this is achieved by calculating the eigenvector, normalised priority weights, of each attribute. (Schniederjans 2004). These eigenvectors are then combined in the supermatrix where every interaction is described in terms of every element it interacts with(Saaty 1999). The supermatrix that is created is via this process is known as the initial or un-weighted supermatrix as it does not yet express the weightings of the overall clusters (Saaty 1999, ;Saaty 2006). A pair-wise comparison matrix must be created to represent the relationship between the clusters, in this case environmental, financial and social. Once this has been completed the calculated eigenvector is applied to the un-weighted supermatrix, this results in a final weighted supermatrix. The eigenvector calculated from the weighted matrix will give the decision maker the prioritised list of elements.

This is a measure of indicator dominance for sustainability for augmentation with the subsystem indicator models and visualisation.

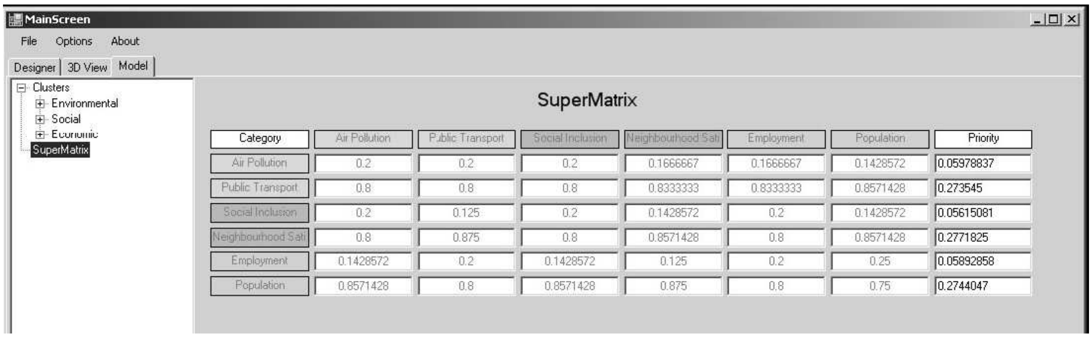

Figure 4. Resulting supermatrix giving priorities/weightings for each indicator value

5 Sub System Models

These are the models that define how the indicators change over time. The indicators currently used by the prototype are housing provision, acceptability, economic output, tourism, energy use and air emissions. As an example we will take the energy use indicator. The current energy use model is an implementation of the standard assessment procedure (SAP) model, which is the governments own standard system for assessing the energy efficiency of buildings. The SAP model allows the stake holder to change a wide variety of variables including glazing type, insulation type, building materials and low energy lighting. The SAP model determines the effect of these variables on the energy use of the building. (Defra, 2008)

The maximum and minimum results for a subsystem are then obtained across all the scenarios being studied. These are used to perform linear maximum-minimum normalization on the results of each subsystem to give a value between 0 and 100.

To determine the sustainability of a specific building, at a given time, in the urban development we would multiply each of the normalized indicator values, obtained from the sub system models at that time point, by the weights/priorities provided by the ANP models. This will give us a quantitative measure of sustainability for each building. It is important to note that our tool does not provide an absolute measure of sustainability but does provide a mechanism to compare how alternative choices i.e. different proportions of residential to commercial properties changes the relative sustainability.

Figure 5, is a schematic summary that describes the steps involved in the sustainability assessment.

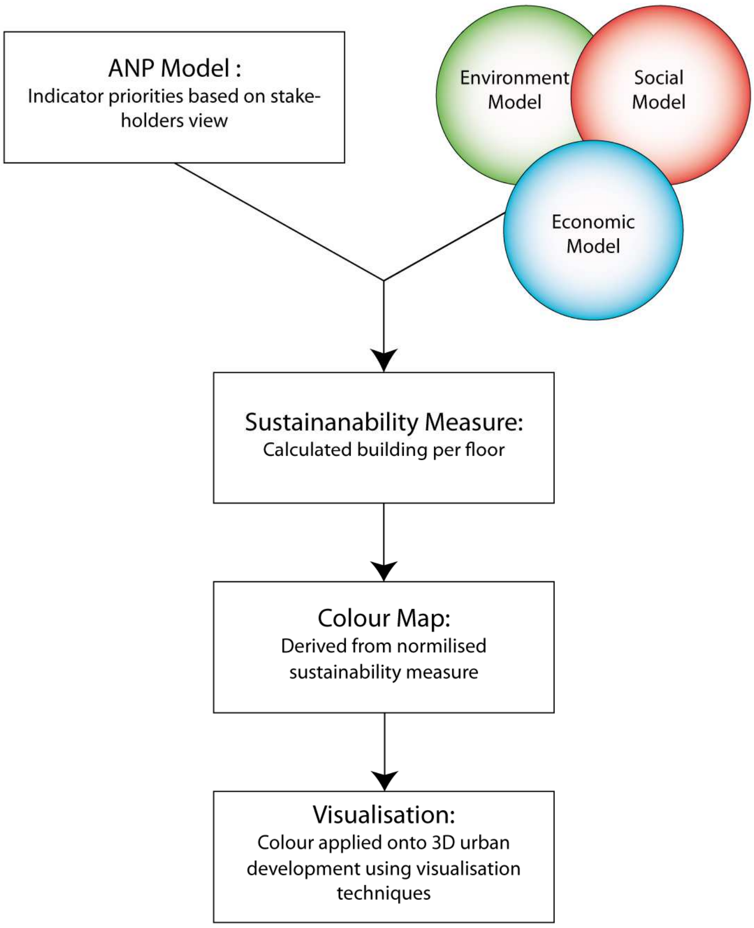

Figure 5. Steps involved in computational and visualisation tool

6 Visualisation Techniques

6.1 Blending

Each element (building, road, water) in the development will now have a sustainability value based on the range of selected indicators. The maps these onto a colour scale using a colour map. The tool is flexible and allows the user to select from numerous colour maps best known for their discriminating abilities (Levkowitz & Herman, 1992). Figure 6 shows the colour scale that is used in the colour maps.

Elements that are blue and red will have a high and low sustainability values respectively.

Figure 6. Sustainability Scale as a Colour Map

Blending is simply the combination of all indicators resulting in a single sustainability value. The colour map above can be used to indicate sustainability.

Figure 7 shows that each floor in the building has a different level of sustainability.

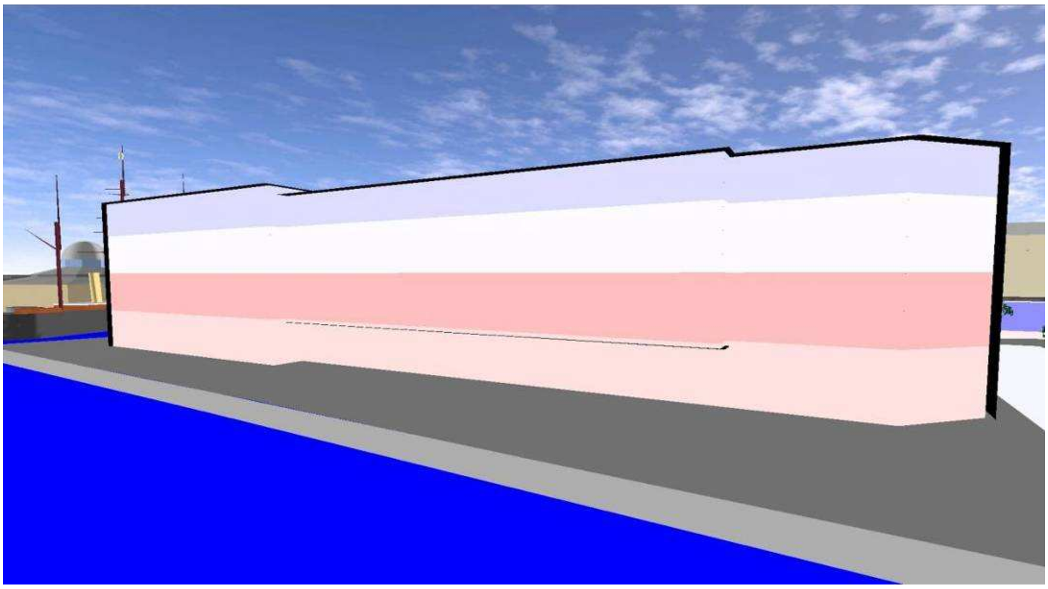

Figure 7. Sustainability Visualisation Using Colour Mapping

6.2 Weaving

Rather than combining all the indicators into a single value it may be possible to preserve some of the underlying information so that we can identify which indicators or clusters are very unsustainable or very sustainable. Here we will use a weaving technique (Hagh-Shenas et al, 2007) that uses a different colour map per indicator (as shown in figures and 8 and 9) to preserve this information.

Figure 8. Sustainability Visualisation Using Colour Mapping of Multiple Indicators

The tool would allow zooming into one building so each indicator value could be determined. This will become more complex as the number of indicators being shown increases, to prevent this over complexity the user will be able to turn off indicators they are not interested in allowing them to mine down to the values relevant to them at that time.

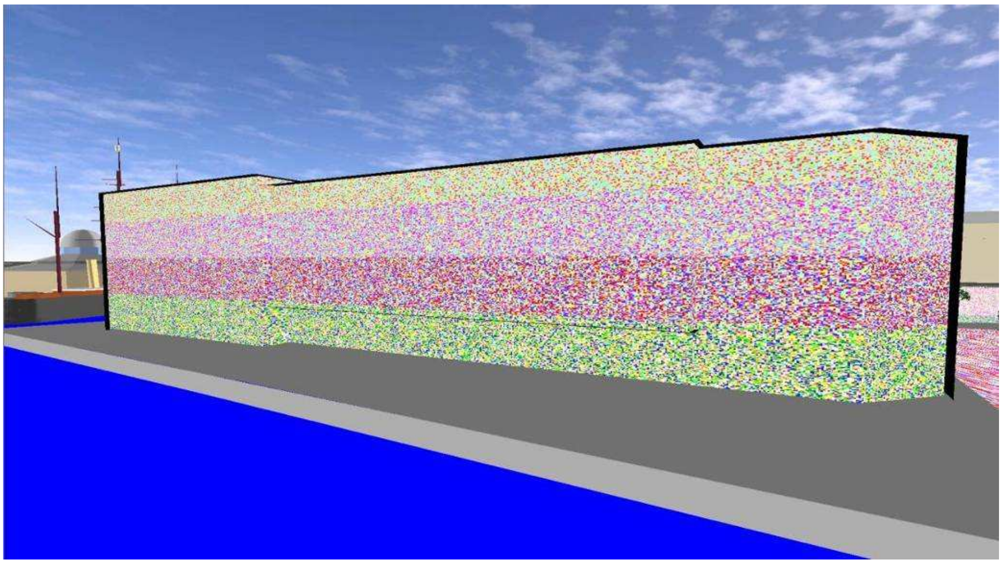

Figure 9. Sustainability Visualisation Using Colour Weaving

6.3 3D Visualisation of the Development

Finally the visualization technique is applied to the 3D development as in Fig 10.

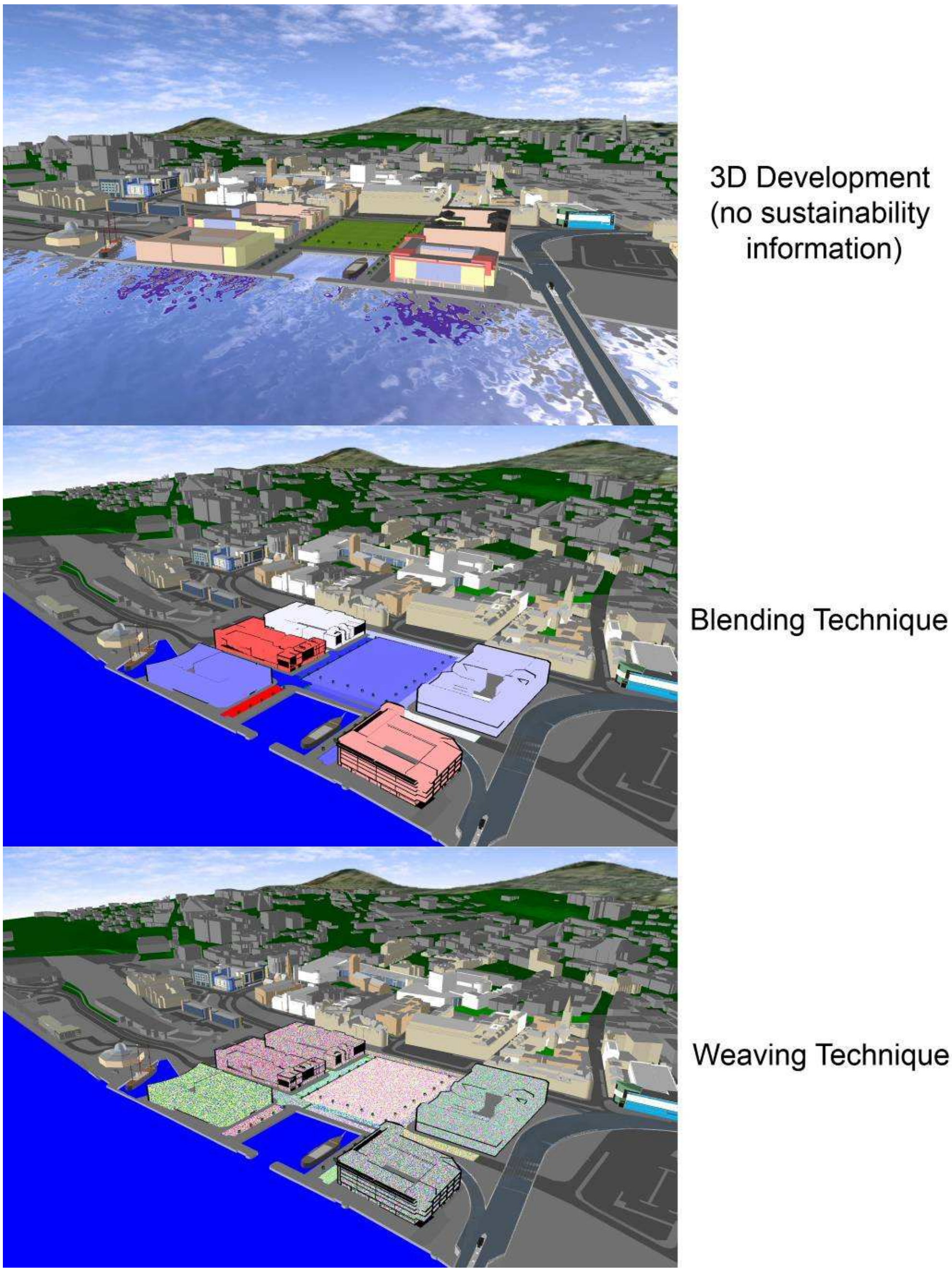

Figure 10. 3D Visualization of development with and without sustainability information

7 Application and Testing of Tool

Testing of S-City VT will now be undertaken using the Dundee Central Waterfront Development Project as a case study. The parallel research work on the implementation of a sustainability enhancement framework for the Central Waterfront Development has informed the choice of sustainability indictors and identified the key stakeholders in the decision making processes.

The final decision in any decision making process is rarely decided by one person, this is equally true in the urban planning domain, because of this our tests will use focus groups to simulate the types of consultation and engagement meetings it is envisaged the tool will ultimately be used in. This group methodology will allow a much better insight into the group decision making process than a questionnaire or solo interview and also provide observational data that would be inaccessible without the interactions found in a group (Morgan 1988). The focus groups used will ideally be comprised of between six and ten members of a single stakeholder group; this will allow the greatest range of opinions without reducing the depth and substance of the discussions (Gilbert 2001).

As usability trials are most effective when participants represent real users performing real tasks (Dumas & Redish, 1999), the stakeholder groups will be presented with two scenarios, running simultaneously using a split screen display, as shown in figure 11. The two chosen scenarios will have different potential levels of sustainability known only to the researchers. The discussions and final conclusion, i.e. which scenario was decided to be relatively more sustainable, of the group is recorded and analysed to assess how the group's ability to make judgements on the relative sustainability of the separate scenarios is guided by the tool.

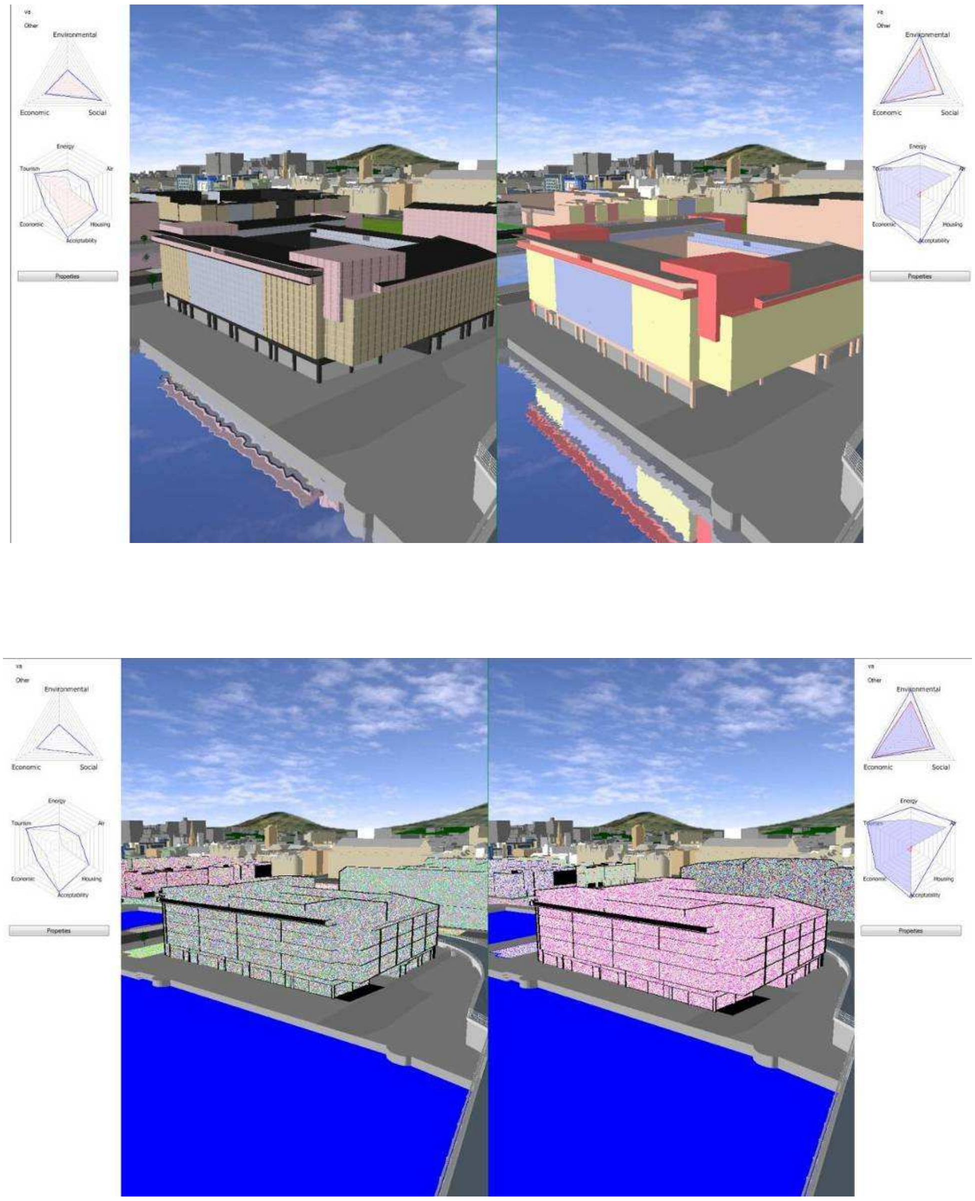

Figure 11: Comparison techniques used for testing.

The testing will not only provide an insight into which of the different visualisation techniques or combination of techniques is preferred by each stake holder group, but also which techniques are most efficient at conveying the complex sustainability information.

The testing methodology was piloted using a test stakeholder group composed of University of Abertay Dundee students of varying levels. The results of the pilot test are detailed below.

<Results to follow>

8 Conclusions

The sustainability techniques provide a visual sensitivity analysis to show how the relative sustainability changes based on stakeholder's opinions and variation of parameters associated with the indicators such as the proportion of commercial to residential properties. The creation of a 3-D virtual environment allows a stakeholder to feel much more a part of the development because they can actually see it come to life. By projecting the results of the simulation model onto a virtual representation of the actual development, S-City VT allows the user to immediately envisage the consequences of any decisions that they make, and the differences in specific scenarios, over a number of years. The use of visualisation techniques in this way 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. Further after usability testing we know which visualization techniques are effective, in terms of conveying sustainability information to a specific stakeholder group. Since the tool is generic it can be easily applied to different complex urban data, for example the indicators can be changed to model demographic change. The indicators can also be extended to include those which influence water movement to enable the probability of flooding for different scenarios could be assessed.

9 References

Ashley R.M., Blackwood D. J., Butler D. & Jowitt P. (2004). Sustainable Water Services – A Procedural Guide, IWA Publishing, London, ISBN 1843390655

Butler D., Jowitt P., Ashley R., Blackwood D., Davies J., Oltean-Dumbrava C., McIkenney G., Foxon T., Gilmour D., Smith H., Cavill C., Leach M., Pearson P., Gouda H., Samson W., Hendry S., Moir J., Bouchart F. (2003). SWARD:decision support processes for the UK. Management of Environmental Quality, 14, 4, 444- 459.

Bouchart, F J-C., Blackwood, D J. & Jowitt, P W. (2002). Decision Mapping: Understanding decision making processes. Civil Engineering and Environmental Systems, 19 (3), pp187-207, ISSN 1028-6608

Defra, (2008). SAP 2005: The Government's Standard Assessment Procedure for Energy Rating of Dwellings. Version 9.81/9.82, Revision 2, BRE, Watford.Eurostat, (2008) Europa-Eurostat database. http://ec.europa.eu/eurostat

T.J. Foxon, G McIkenny, D Gilmour, et al (2002) Sustainable Criteria for Decision support in the UK water industry. Journal of Environmental Planning and Management, 45 (2), 258-301, 2002

Geldof, (2005). "Integrated water management and complexity". Deventer: Tauw Deventer. ISBN 90-76098-04-2

Gilmour D, Blackwood D., Banks L., & Wilson, F. (2007). A Sustainability Enhancement Framework for the Dundee Central Waterfront Development. Proc. International Conference on Whole Life Urban Sustainability and its Assessment, Glasgow Caledonian University, June.

Hagh-Shenas, H. et al. (2007). Weaving Versus Blending: a quantitative assessment of the information carrying capacities of two alternative methods for conveying multivariate data with color. IEEE Transactions on Visualization and Computer Graphics. pp.1270-1277

Hull, D. A. & Tricker R. C. (2005). Assessing Barriers to sustainable UK urban transport solutions. Proceedings of the Institution of Civil Engineers, Engineering Sustainability, 158, pp171-180

Isaacs, J. P, Falconer, R, Blackwood, D. (2008) A Unique Approach to Visualising Sustainability in the Built Environment. Proceedings of the International Conference Visualisation, 9-11 July 2008, pp3-10.

Kurt F. (2004). Cybernetics and Systems, Vol. 35. No. 5-6, pp 455-485

Levkowitz, H. & Herman, G. T. (1992). Color scales for image data. IEEE Computer Graphics and Applications. 12(1): pp.72-80.

Morgan, D. L. (1997). "Focus Groups as Qualitative Research". London: Sage Publications, ISBN 0761903437

Olsen. L., (2004). Sustainability reporting: and anchor, not the answer. Engineering Sustainability 157 June 2004 issue ES2 pp. 63-64.

McAllister (2005). Wellbeing Concepts and Challenges. Discussion paper. Sustainable Development research Network, December 2005

Saaty, T. L. (1990). How to Make a Decision: The Analytic Hierarchy Process. European Journal of Operational Research. 48(1): pp.9-26.

Saaty, T. L. ed. (2006). The Analytic Network Process. Melbourne: Idea Group Inc.

Sahota P.S. & Jeffery P. (2005). Decision support tools: moving beyond a technical solution. Proceedings of the Institution of Civil Engineers, Engineering Sustainability, 158, pp127-134

Schniederjans, M. J. 2004. Information Technology Investment : Decision-Making Methodology. Singapore: World Scientific Publishing Company.

Shellito, B. A., Dixon, J., Inge, C. and O'Neal, J. (2004). Tourism Analysis, Vol. 9. No. 3. pp167-178

Semboloni F., Assfalg, J. Armenei, S., Gianassi, R. & Marsoni F. (2004) Computers, Environment and Urban Systems, Volume 28, No. 1. pp 45-64.

Simon 2003. Sustainability indicators. in Neumayer, Eric, Eds. Online Encyclopaedia of Ecological Economics (OEEE). International Society for Ecological Economics.

Smith, H., Gilmour, D., McIlkenny, G., et al. (2002). Decision support processes for the UK water industry – The SWARD Project. The 2002 international sustainable development research conference, University of Manchester , 8-9 April, 2002.