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The Role of Visualisation in Effective Sustainability Assessment

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ABSTRACT

Sustainable decision making in urban design is a complex and non-linear process that requires the interaction of a wide variety of stakeholders. A number of sustainable decision support tools have previously been developed but a major barrier to the implementation of these tools is the complexity of the environment in which decisions are made. In particular, engagement with the general public throughout the decision making process presents challenges. These include communicating the complex and interdependent facets of sustainability and also demonstrating the short and long term implications of alternative courses of action.

This paper describes the underlying concepts of a prototype visualisation tool (S-City VT) that will allow stakeholders to understand, interact with and influence decisions made regarding sustainability of urban design. The Dundee Waterfront Development Project will be used as a case study. The S-City VT simulation will model the relationship between the various sustainability indicators and the effect of choosing a particular set of indicators will be brought to life through an animation-based simulation. The model can also be used to identify possible trade-offs between the facets of sustainability.

Key words: Urban Sustainability, Virtual City, Modelling, Visualisation

1. INTRODUCTION

Sustainable decision making in urban design is a complex and non-linear (iterative) process and requires the interaction of wide variety of stakeholders. Effective sustainability assessment is, therefore, 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 there applications are dominated by the perceptions of “expert” decision makers (e.g. planners, architects, and design engineers).

Many researchers have concluded that a major barrier to the development and implementation of tools to support sustainability assessment in urban design is the complexity of the environment in which decision are made (Bouchart, et al, 2002, Hull &Tricker, 2005). In particular, engagement with the general public throughout the urban design 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. The flow of information between the “expert” decision makers and the wider stakeholders communities is shown in figure 1.

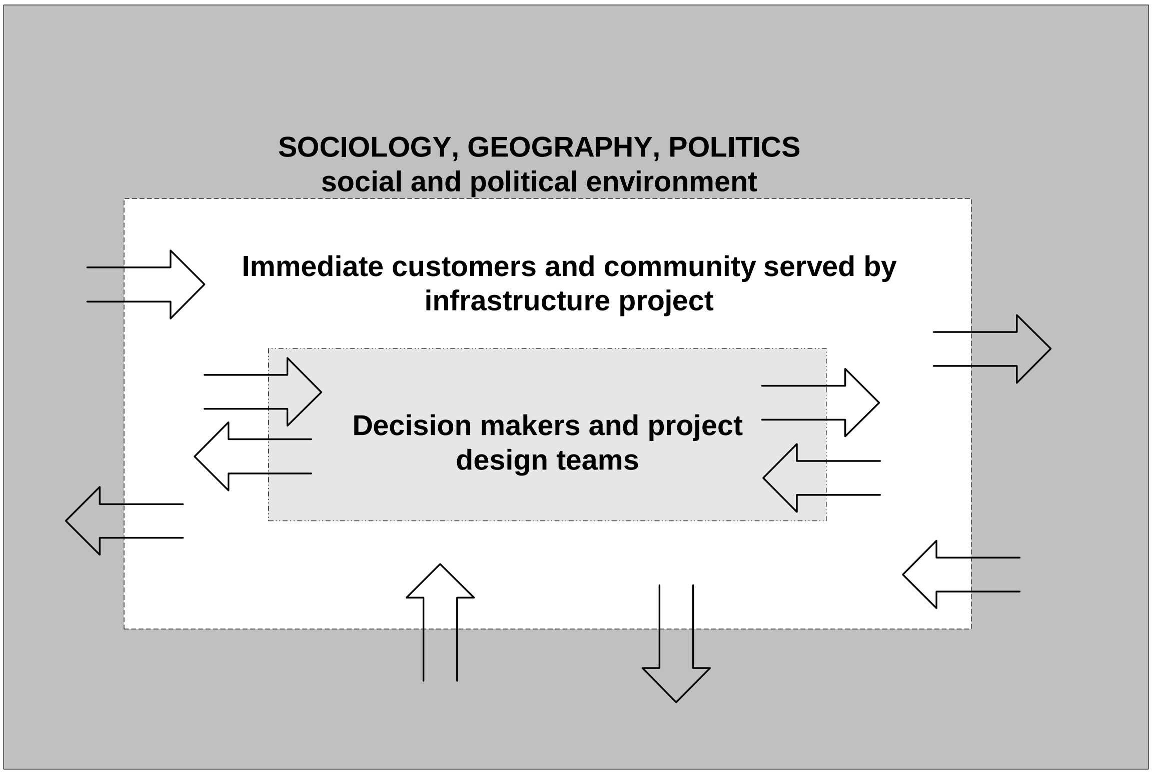


Figure 1: Stakeholders, boundaries and information flows (Adapted from Gilmour et al., 2005).

The centre of the figure (the first tier) represents the decision makers and project design teams, usually technical or planning specialist within local or national government organisation or within consultants engaged by these bodies. The second tier represents the immediate customers and the communities served by the infrastructure and the third tier represents the societal, geographical and political frameworks within which the customers and communities are located. The arrows represent the required information flows across the possible boundaries if all aspects of sustainability are to be considered by the decision makers and design teams.

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 a robust assessment of sustainability within 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.

2. HIVE PROJECT

The Haptic Intelligent Virtual Environment (HIVE) has been developed at the University of Abertay Dundee to create an immersive visualisation suite. The aim of the HIVE is to allow a user or group of users to interact fully with the virtual environments created. The research project described here is one of four interdisciplinary studies that will use the HIVE facility to develop novel visualisation approaches for complex data sets. Specifically, an aim of the research is to develop and validate a prototype visualisation tool that will enable the engagement of wider stakeholders, who would not otherwise understand the overall complexity and interaction between the facets of sustainability, to allow iteration on the virtual development before the real development is created. The decisions will be brought to life through an animation based simulation through time of the case study project. The research team will use the HIVE to develop a prototype visualisation tool that will enable stakeholders to understand, interact with and influence decisions made on the sustainability of urban design, based on a major urban redevelopment case study.

3. DUNDEE CENTRAL WATER FRONT DEVELOPMENT.

In 1998, the Dundee City Council and Scottish Enterprise Tayside formed the Dundee Partnership to look at potential options for re-developing the Dundee Central Waterfront to enhance its integration with the City Centre. The outcome was a 30-year Masterplan to completely remodel the area as shown in Figure 2 to remove one of the last remaining major blights on the city's image and townscape. It will create a high-quality, mixed-use, riverside urban-quarter right in the heart of the city. Dundee City Council have adopted this Masterplan for the purposes of controlling future development in the Central Waterfront area; all applications for planning permission will be expected to be in conformance with the Masterplan in order to protect the long term development potential of the area.

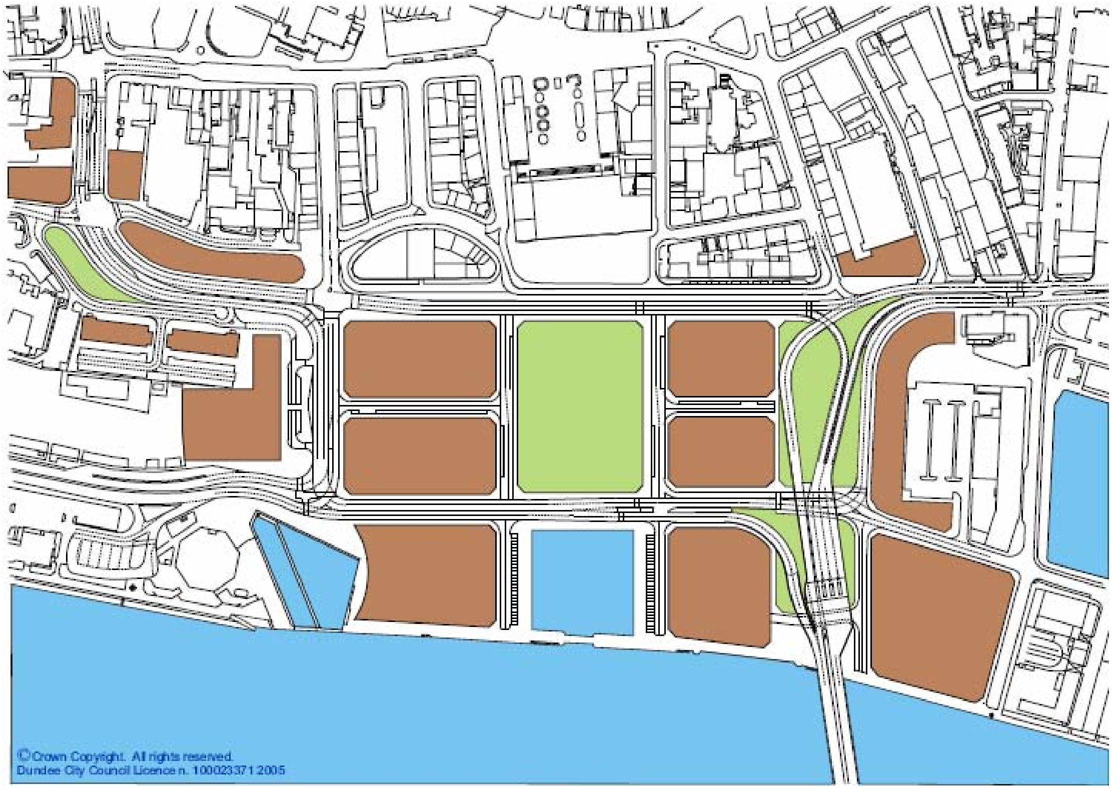


Figure 2: Dundee Central Waterfront Development Plan.

The main components of the development are; the extension of the city centre down to the waterfront, the creation of a new grid iron street pattern, improved provision for walking, cycling and buses, the reduction of the effect of cars and parking, the removal of some of the Tay Road Bridge ramps, the creation of a pair of east/west tree lined boulevards, provision of sites for a variety of mixed use developments, the formation of a major new civic space and re-opened dock, the provision of a new rail station and arrival square. The research team has been commissioned by Dundee City Council to develop a sustainability enhancement framework for the development (Gilmour et al., 2007) and the visualisation tool will form part of the framework.

4. REVIEW OF EXISTING VISUALISATION MODELS

A number of decision support tools have been created to address the complex issues involved in sustainability assessment within the decision making process for urban developments. There has been huge effort and resources put into creating these DSTs, yet despite this most are never or hardly ever used (Sahota & Jeffrey, 2005). There are a number of reasons for this lack of uptake, usually the decision support tools are designed for a single purpose, to investigate transport issues for example, or that the systems become so generic that any detailed results are lost. Some existing decision support tools are outlined below.

4.1 The BEQUEST Toolkit

The BEQUEST (Building Environmental Quality Evaluation for Sustainability through Time) toolkit is a modular system designed “to support decision maker concerned with urban sustainability” (Bequest, 2001). The toolkit is composed of 4 modules: protocol, assessment methods, advisors and glossary.

BEQUEST is a web-based system that provides generic information about sustainable development. The toolkit provides the users with textual results such as assessment techniques, which can be used to examine the development at different stages or a list of advisors who could advise about the relative sustainability of a specific part of the development. The toolkit provides a good level of integration across the problem domains; however it does not contain any scenario, impact analysis or policy options.

4.2 STEEDS (Strategic Transport Energy Environment Decision Support)

STEEDS is a “Decision Support System (DSS) able to assist the policy makers in exploring the influences on market take-up of different transport technologies” (Brand et al. 2001). Steeds is based around a set of scenario and policy options, combined with five interacting subsystem models, the results of the model are then collected as a set of alternatives. The alternatives provided by the model can then be investigated in graph form or evaluated using multi-criteria analysis (Brand et al. 2001).

Although the subsystems approach STEEDS implements, provides extensive scenario and policy options coupled with impact analysis, these are based solely on environmental aspects of the transport sector. This severely limits the systems effectiveness in anything but transport developments, and even then STEEDS does not account for social and economic aspects.

4.3 SUTRA (Sustainable Urban Transportation)

“The primary objective of SUTRA is to develop a consistent and comprehensive approach and planning methodology for the analysis of urban transportation problems, which helps to design strategies for sustainable cities” (SUTRA, 2006). SUTRA is a web-based system which uses an indicator based simulation model combined with social, environmental and economic impact analysis. (SUTRA, 2006). Similar to STEEDS, SUTRA provides the user with extensive scenario and impact analysis support however Sutra's main advance over other decision support systems is the way in which the results are presented to the user.

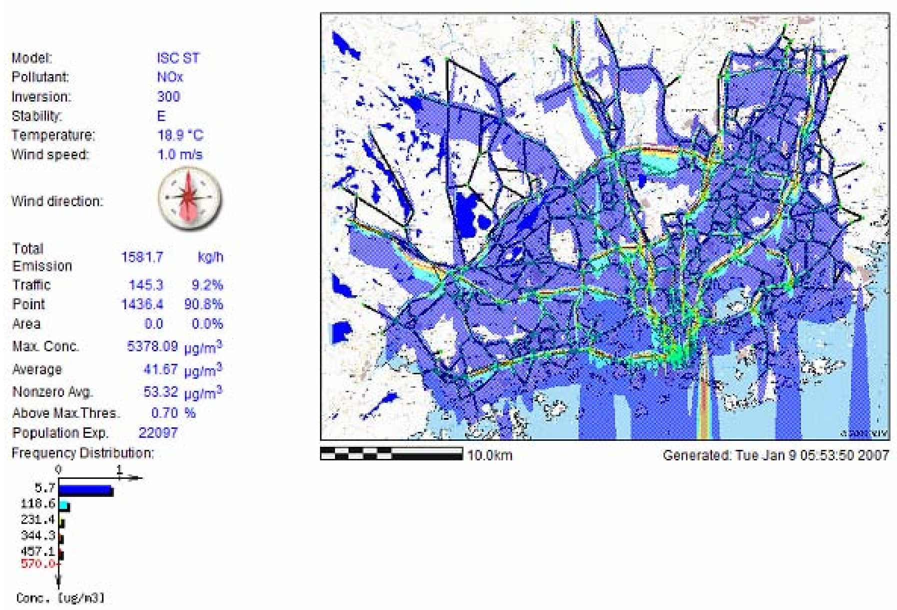


Figure 3: SUTRA Simulation Screen (SUTRA, 2006).

Using SUTRA the user is no longer presented with complex graphs or tables but instead can view the impact of decisions they have made in real-time, projected on a map of the area or city being investigated. Figure 5 shows an example simulation of NOx release from traffic in Helsinki. This approach of animated, visual results opens the system to use by non-expert stakeholders, e.g. the general public. SUTRA is however limited due to the fact it is only designed to simulate transport issues and not overall urban development, there is also little suggestion or ranking of alternatives.

4.4 AUSTIME (Assessment for Urban Systems Through Integrated Modelling and Exploration)

The AUSTIME methodology was designed to combine "systems analysis, sustainability assessment based on system thresholds and multiagent simulation for scenario exploration" (Daniell et al, 2005). The methodology describes how to create a decision support system to provide sustainability assessment of a specific scenario.

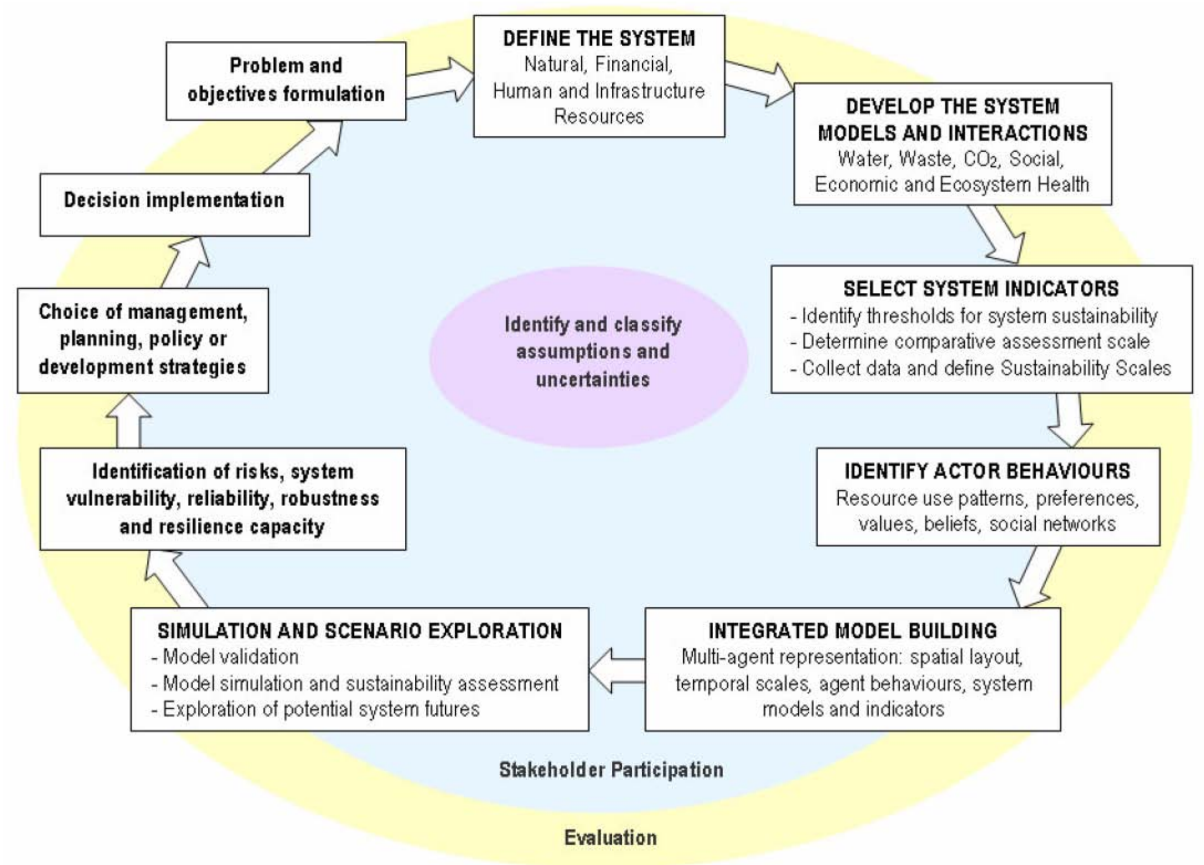


Figure 4: AUSTIME development methodology. (Daniell et al, 2005).

AUSTIME was used to create a prototype model and perform a sustainability assessment of a development in Adelaide, Australia called Christie Walk. The model produced contained six sub-system models (water, CO_2, waste, eco-system health, economic and social) each of which could act independently to simulate their respective aspects, the sub-systems were then combined to create a single integrated model which could simulate the sustainability of the development as a whole. The results of the prototypes application to the Christie Walk development were used to show, using graphs, what affects changes in some of the sustainability aspect , water use or CO_2 output for example, would have on the developments over-all sustainability. (Daniell et al, 2005).

The prototype created using the AUSTIME methodology for the Christie walk case study seems to effectively simulate the sustainability of the development for the aspects which were included in the model. The prototype however was weighted towards environmental aspects possibly due to the fact that the Christie walk development was specifically designed “demonstrate the vision for an ecological city” (Daniell et al, 2004). The prototype also used very few indicators, one in each subsystem, and only allowed the simulation of changes in these indicators on a fixed development. There was, for example no provision for moving an entire building, or changing a building material and exploring the effect of such changes on the development's sustainability. The user would be required to know the affect of their actions on the included indicators to enable them to determine the results of their actions, this makes the system extremely hard, if not impossible, to be used effectively by non experts.

5 S-CITY VT

The review of the existing sustainability decision support tools has shown that there is no single tool which can effectively support the decision making process for every aspect of a whole sustainable development. This project aims to create a prototype tool, S-City VT which will allow stakeholders, involved in the urban planning process to understand, interact and influence decisions made regarding the development of sustainable urban environments. As a proof of concept the prototype will attempt to model the sustainability of the regeneration development of Dundee’s waterfront.

The development of the prototype is twofold. Initially a simulation model will be developed which integrates and combines the sustainability indicators from the various social, economic and environmental domains. Secondly a front-end visualisation tool will be developed which will demonstrate the evolution of a ‘potential’ development for a given set of indicators.

5.1 Prototype Requirements

The development of the prototype will adhere to a number of criteria outlined in Kapelan et al. 2005. been used to create a number of requirements which the prototype should fulfil.

The requirements for the simulation model are to enable:

- a high level of integration across different domain criteria and indicators;
- detailed impact assessment of proposed action and developments;
- modelling of possible future urban scenarios;
- the inclusion of pre-built policy options, government & council laws or guidelines;
- an evaluation of solutions to problems based on a user selected criteria ranking system;
- calibration and validated using sufficient quantity/quality of observed data;
- computational efficiency without reducing usefulness.

The requirements for the simulation model are that it should:

- Include 3D/virtual reality visualization techniques.
- Provide spatial and temporal scales.
- Include a ‘rich’, graphical user interface to allow use by non-experts.

- Allow the possibility of group decision making and communication.

5.2 Development of the Prototype

Figure 5 shows the structure of a prototype system which fulfils the requirements outlined in the previous section.

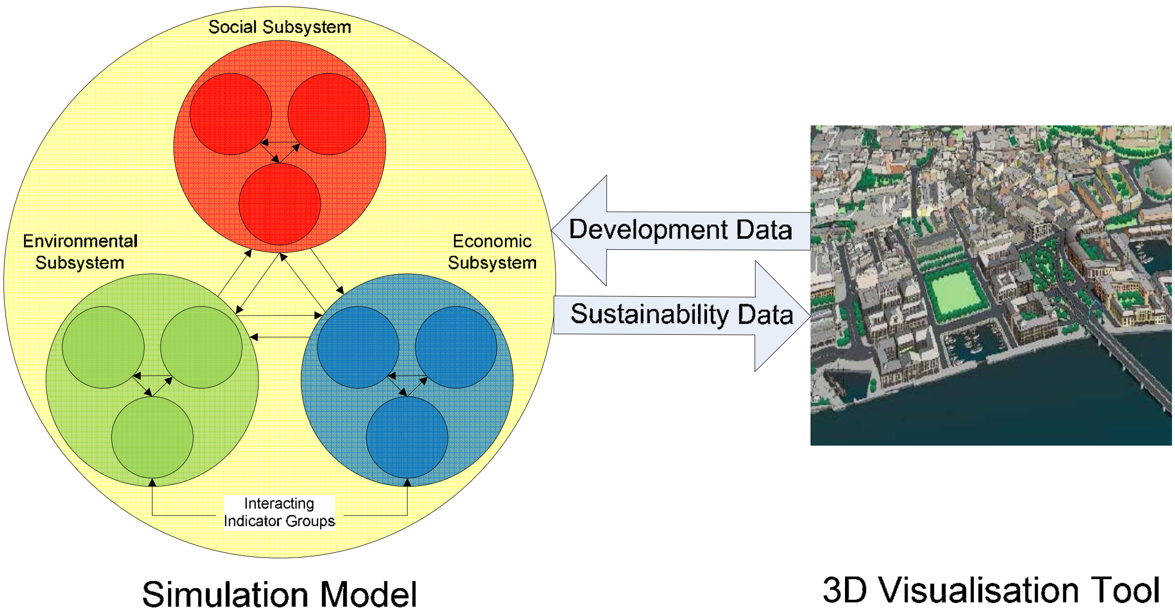


Figure 5: Structure of the proposed prototype.

The development of this prototype will require the following steps.

Identification of indicators

The economic, social and environmental sustainability criteria will be sourced directly from Dundee City Council. This will involve discussions with the council stakeholders about which criteria they require and whether the modelling and visualisation of these criteria is possible. The indicator values used to measure these criteria will also come mostly from council data. However it may be necessary to acquire some of the data, especially for social aspects, from other sources, such as through the development and use of questionnaires for the general public.

Identification of indicator scales and weightings

The indicator data will be used to develop scales of sustainability for each indicator. An example of how this can be achieved is shown in fig 4. Each indicator will also be examined to determine how strongly it affects the other indicators, i.e. its weighting.

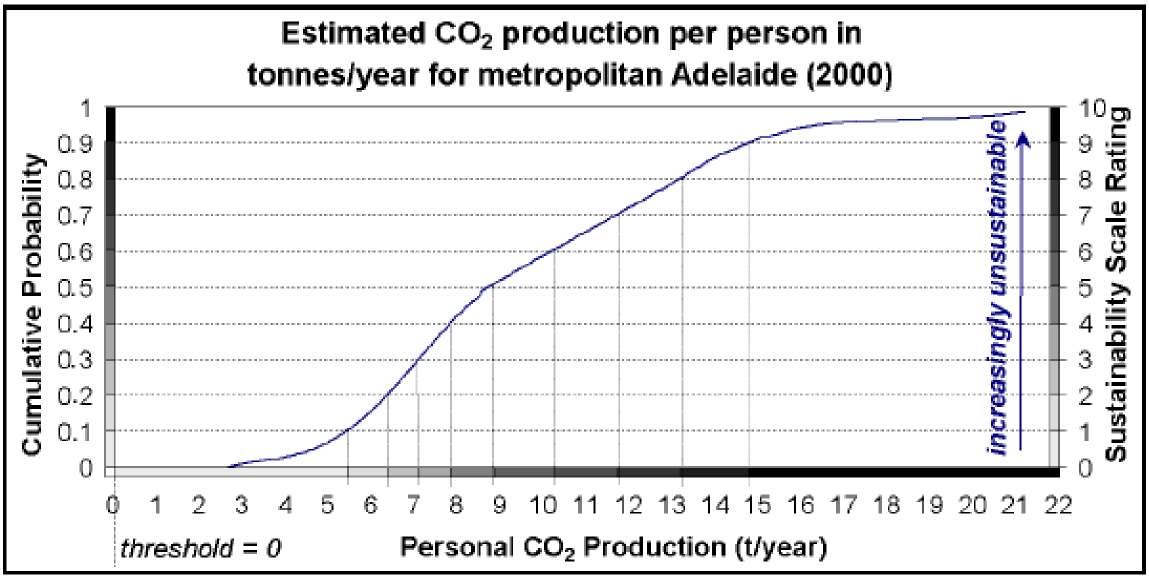


Figure 6: Example indicator scale. (Daniell et al, 2005).

Development of subsystem models.

From the indicator data collected, relationships and interactions among the indicators will be identified. These interactions will be described by algorithms which will model how changes in one indicator affect the others, effectively creating small models of each part of the system. It is envisaged that subsystems will be developed for different aspects of the overall system. There will be at least 3 subsystems relating to social, economic and environmental indicator groups.

Determination of actor behaviour.

At this point in the model development it will be necessary to determine how the behaviour of the actors (residents or workers), who will be using/living in the proposed development will affect the model and the indicators used. This investigation may include more public surveys to determine behaviour patterns of the general public, for instance, how far a person is happy to walk to resources such as bus stops or shops. These actor behaviours will affect the simulation model as a whole and may not be adequately described by a single subsystem.

Development of integrated model.

An integrated model can now be designed by combining all the smaller system models together with the affect of actor behaviour. It is hoped that it will be possible to view results for the entire development area (the waterfront) and allow a scaling ability down to a single street or building. Temporal scales should now also be considered; the model should allow data to be modelled from the present day up to the project proposed completion date, approximately 30 years time. (Dundee City Council, 2001).

Exploration & development of scenario options.

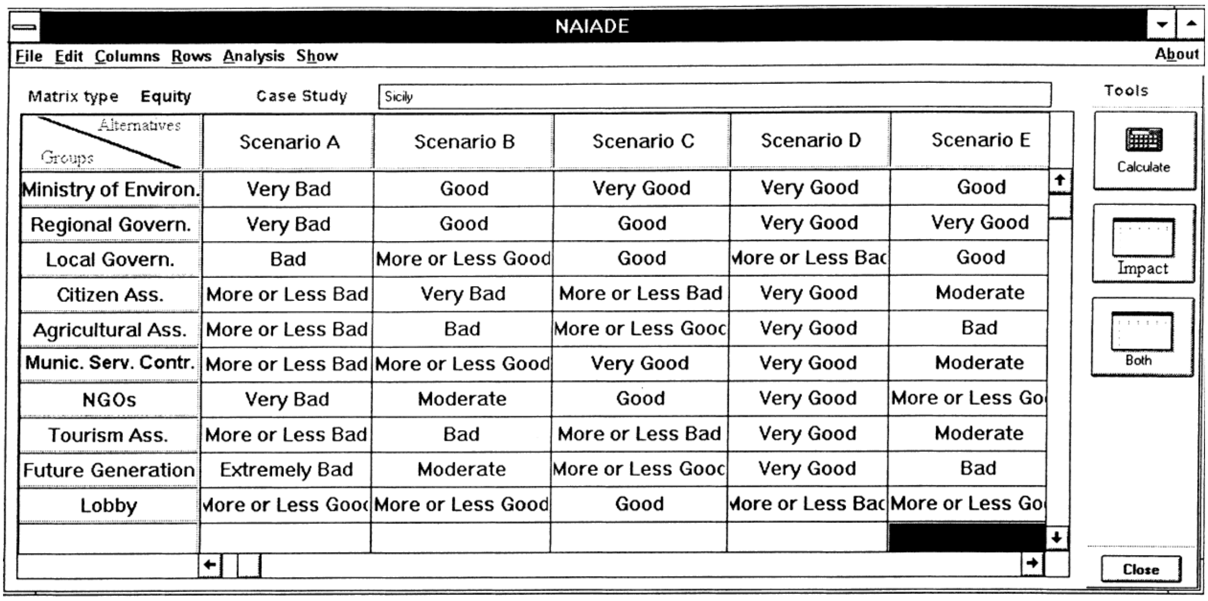
The model will now be able to simulate the current system with no changes; however it is the purpose of the prototype that will be able to assist in planning decisions of the stakeholders involved in the development. As this is the case it is necessary to introduce scenario modelling and impact assessment components into the integrated model. As has already been stated in the requirements, the model should contain a number of built-in scenarios. The development of the built-in scenarios will require research into the affects, or projected affects, of different types of global scenarios such as nearby factory closures or global warming, or local scenarios such as the position of traffic lights or residential buildings, on the indicators. These built-in scenarios will allow the stakeholders to enter the minimum amount of data, such as position of traffic lights or projected temperature rise, but receive a detailed description of the effect that these scenarios will have on the development. (Brand et al., 2001). The model must also allow a stakeholder to create their own scenarios, such as drastic changes in population types. This will involve a detailed user input describing the affect of the scenario on one or more criteria, the model will then create the scenario and determine its affects on the other indicators and so the over-all sustainability of the system. (SUTRA, 2006).

Investigation and Development of policy options.

The model must be able to describe the affect of changes in government policy on the indicators and hence their affect on the proposed development. Should the council for example introduce a citywide recycling policy, the model should be able to show the affects that this policy will have. Proposed government and council policies should be investigated to determine how they would affect the indicators and the subsystem models. The model should also allow the user to create their own policies to describe the affects of unforeseen government policy introductions throughout the lifetime of the development. Again this will require detailed user input on how the new policy will affect one or more of the indicator groups.

Investigation & Development of criteria ranked solutions.

The impact assessment component of the model will display the affect of a number of solutions for proposed decision and attempt to rank them based on criteria selected by the stakeholder. This will allow the stakeholder to determine the best possible solution for them. Figure 7 shows a decision matrix, which details the suitability of a number of different scenarios for different types of stakeholders.



Alternatives / Groups	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E
Ministry of Environ.	Very Bad	Good	Very Good	Very Good	Good
Regional Govern.	Very Bad	Good	Good	Very Good	Very Good
Local Govern.	Bad	More or Less Good	Good	Nore or Less Bac	Good
Citizen Ass.	More or Less Bad	Very Bad	More or Less Bad	Very Good	Moderate
Agricultural Ass.	More or Less Bad	Bad	More or Less Gooc	Very Good	Bad
Munic. Serv. Contr.	More or Less Bad	More or Less Good	Very Good	Very Good	Moderate
NGOs	Very Bad	Moderate	Good	Very Good	More or Less Go
Tourism Ass.	More or Less Bad	Bad	More or Less Bad	Very Good	Moderate
Future Generation	Extremely Bad	Moderate	More or Less Gooc	Very Good	Bad
Lobby	Nore or Less Gooc	More or Less Good	Good	Nore or Less Bac	More or Less Go

Fig 7: Example decision matrix (Hasstrup et al, 1997).

Due to the highly complex components, the indicator interactions, of each decision, the development of the impact assessment component of the model will require the investigation of different ranking techniques. As the suitability of each scenario will not be based on single factor, the ranking/organisation of the possible scenarios will require the use of complex algorithms. This may include the use of a genetic algorithm, where the solution of best fit may be found from a given data set. (Carson & Maria, 1997) Or the use of a ranking technique such as PROMETHEE (Brands & Vincke, 1985) or ELECTRE TRI. (Mousseau et al, 2000).

Model optimization

The inherent complexity of sustainable development as a consequence of the large number indicators, leads to the model, in particular the indicator interaction algorithms being computationally intensive. While it would be possible to specify a reasonable computer specification required to run the model it may also be possible to distribute some of the processing required throughout a grid system, such as the National Grid System (NGS) or the European Grid (EG). (NGS, 2006). This distributed processing would allow much faster manipulation of the data and reduce the resource use on computer running the prototype. However the effectiveness of this distribution system would have to be investigated.

Development of 3D Engine

While the development of the mathematical model can be applied to the AUSTIME methodology, the development of the 3D visualisation tool is not so clear-cut. There are numerous possibilities in which to develop a 3D virtual world that will represent Dundee's waterfront. It must first be decided which 3D technology to use, the main options being Microsoft's DirectX , open source OpenGL or the Virtual Reality Mark-up Language (VRML). All of these technologies will allow the creation of a representation of the waterfront development; however VRML is designed as a static view for city visualisation to be viewed through a specialised web browser and so does not adequately allow for the design of real-time scenarios selected by the user (Web 3d, 2006). Both DirectX and OpenGL will allow advanced techniques such as particle effects and sound, to be used in the visualisation. This will allow factors such as air pollution to be shown as clouds of particles or for traffic noise to be represented through an audio interface. At present DirectX seems to be the most viable option due to its close connectivity to the .Net languages which will be used in the implementation of the mathematical model, as DirectX allows the use of complex low-level hardware effects, which will reduce the overhead on the computers processor (CPU) by processing the complex mathematical (matrix) operations solely on the machine's Graphics Processing Unit (GPU). (MSDN, 2006). To create the virtual waterfront it will be necessary to acquire some information about the area. This will include building and landscape data about the area to be developed. There are a number of methods by which the virtual world can be created depending on the data collected. Some possibilities include;

- Lidar data – The heights of buildings are determined by airborne laser imaging, these height maps can then be converted into meshes representing the building in the area of development (BEX, 2006).
- Panoramic Photography – Panoramic photographs are taken of the area to be developed and 3D views are created from these photographs (Katsushi et al, 2002).
- Architectural Models – CAD Models for the proposed development will be created by the developments designers to create a static view of the development. These models can be used to create the dynamic, walk through environment required by the visualisation tool.

There will be much more research needed into the creation of virtual worlds before a final decision is made on how the 3D world the visualisation tool uses will be implemented.

GUI Development.

The graphic user interface (GUI) to use the visualisation tool should be developed with constant feedback from the users to ensure that it allows easy access to the complex functions both of the model and of the visualisation tool. Standard practices regarding ease of use will also be used during the GUI development; this will entail discussions with the stakeholders, the council, about how they think the GUI should be structured to most benefit them.

Implementation of group decision making.

The possibility of group decision making is an important aspect as it will allow stakeholders to participate in the decision process wherever they are physically. One possibility is to use the Nation Grid System to store all the data being used by the prototype, this approach will allow any number of prototypes to access the same data no matter where the prototype is actually being executed. This approach would also allow the possibility of stakeholders submitting different possible scenarios to the central storage location, which other stakeholders could then explore. (NGS, 2006)

6. CONCLUSIONS

It is clear that due to the complexity of developing sustainable urban developments, decision support tools will play an important role in their creation. Using the existing tools it is possible to describe small parts of a development, such as transportation or to describe a single feature e.g. the environment. It is however evident that no complete solution exists, and even the simultaneous use of a number of decision tools will not adequately overcome this problem. The AUSTIME development method does seem to provide a viable way of creating a decision support tool, although the only tool created using this method was tied to a single specialised residential development and so its benefit to a more generic urban scenario cannot yet be determined.

It is extremely important that the decision making process be open and available to as many of the stakeholders as possible, this should include everyone from the financial investors to the general public. Decision support tools do exist which will allow a stakeholder to view the consequences of their decisions, by projecting the results onto a representation of the actual development. This makes the tool accessible to non-expert decision makers as they can easily see the affect of their decision. However currently there are few, if any decision support tools which include an immersive virtual environment in which the development and the consequences of decisions made can be seen in situ.

The S-City VT prototype hopes to overcome the drawbacks of current decision support tools by combining an integrated simulation model with a visualisation tool. The use of an integrated simulation model, based on the sustainability indicators outlined by the government and Dundee City Council, will allow the impact of any decision to be determined across all the sustainability aspects (social, environmental and financial). What will set SCity-VT apart from currently existing decision support tools will be its use of 3D technologies in displaying the results of the model. By creating a 3D virtual representation of a proposed development, a stakeholder will be able to ‘fly’ through an animated simulation of their development and see the real life consequences of their proposed decisions over a number of years. This approach will empower the stakeholders by illustrating the possible trade-offs between the facets of sustainability in an easily understandable form and in a virtual environment they will recognise as their development.

7. REFERENCES

BEQUEST. 2001. The BEQUEST Toolkit. [online]. Available from: http://www.research.scpm.salford.ac.uk/bqtoolkit/index.htm [Accessed 9 January 2007].

BEX. 2006. Building Extraction from digital surface models. [online]. Available from: http://www.ipb.uni-bonn.de/ipb/projects/bex/bex.html [Accessed 13 November 2006].

Brand et al., 2001. STEEDS: A strategic transport–energy–environment decision support. *European Journal of Operational Research.* 139 (2002), 416–435.

Brans, J.P & Vincke, PH., 1985. A preference ranking organisation method. *Management Science*. 31(6), pp.647-656.

Bouchart, F J-C., Blackwood, D J. and Jowitt, P W.,2002. Decision Mapping: Understanding decision making processes*. Civil Engineering and Environmental Systems*, 19 (3), 187-207, ISSN 1028-6608.

Carson, Y & Maria, A., 1997. Simulation optimization: methods and applications. Proceedings of the 1997 winter simulation conference*,* 118-126.

Daniell, K et al., 2005. Integrated urban system modelling: methodology and case study using multi-agent systems. MODSIM 2005 International Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand. December 2005, 2026-2032.

Defra, 2005. Securing the future: The UK government sustainable development strategy. Department of Environment, Food and Rural Affairs.

Dundee City Council, 2001. Dundee central waterfront: Development masterplan 2001 – 2031. Planning and Transportation Department, Dundee City Council.

Foxon, T.J., McIlkenny, G., Gilmour, D., Oltean-Dumbrava, C., Souter, N., Ashley, R., Butler, D., Pearson, P., Jowitt, P. and Moir, J., 2002. Sustainability Criteria for Decision Support in the UK Water Industry. Journal of Environmental Planning and Management 45 (2), 285-301.

Geldof, 2005. Coping with complexity in integrated water management - on the road to interactive implementation, Tauw bv Deventer ISBN 90-76098-04-2.

Gilmour, D. J., Blackwood, D. J., Picken K. 2005. Stakeholder involvement in wastewater treatment design. Proceedings of the 10th International Conference on Urban Drainage*,* Copenhagen, August 21 – 26th.

Gilmour D., Blackwood D., Banks, L., Wilson, F., 2007. A sustainability enhancement framework for the Dundee Central Waterfront development. Proceedings of the International Conference on Whole Life Urban Sustainability and its Assessment Glasgow, 27 – 29 June 200.7

Hasstrup et al., 1997. A decision support system for urban waste management. *European Journal of Operational Research.* 109(1998), 330-341.

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.

Kapelan et al., 2005. Decision support tools for sustainable urban development. *Proceedings of the Institution of Civil Engineers, Engineering Sustainability.* September 2005. 158(ES3), 135-142.

Katsushi et al., 2002. Constructing virtual cities by using panoramic images. *International Journal or Computer Vision.* 58(3), 237-247.

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

Mousseau et al., 2000. A user-orientated implementation of the ELECTRE-TRI method of integrating preference elicitation support. *Computer & Operations Research.* 27(2000), 757-777.

MSDN, 2006. Microsoft Development Network. [online]. Available from: www.msdn.com [Accessed 13 November 2006].

NGS, 2006. National Grid Service. [online]. Available from: www.grid-support.ac.uk [Accessed 13 November 2006].

Sahota & Jeffrey, 2005. Decision-support tools: moving beyond a technical orientation. *Proceedings of the Institution of Civil Engineers, Engineering Sustainability.* September 2005. 158(ES3):pp. 127-134.

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

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

SUTRA, 2006. SUTRA: Sustainable Urban Transportation. [online]. Available from: http://www.ess.co.at/SUTRA/ [Accessed 13 November 2006].

Foxon T.J. et al., 2002. Sustainability criteria for decision support in the UK water industry. *Journal of Environmental Planning and Management.* 45(2):pp.285-301.

Web 3d, 2006. Web 3D Consortium. [online]. Available from: www.web3d.org [Accessed 13 November 2006].