An interactive visual decision support tool for sustainable urban river corridor management

Lewis Gill

Vikas Kumar

Eckart Lange

D. N. Lerner

Ed Morgan

See next page for additional authors

Presenter/Author Information
Lewis Gill, Vikas Kumar, Eckart Lange, D. N. Lerner, Ed Morgan, Daniela Romano, and Ed Shaw

International Environmental Modelling and Software Society (iEMSs)
2010 International Congress on Environmental Modelling and Software
Modelling for Environment's Sake, Fifth Biennial Meeting, Ottawa, Canada
David A. Swayne, Wanhong Yang, A. A. Voinov, A. Rizzoli, T. Filatova (Eds.)
http://www.iemss.org/iemss2010/index.php?n=Main.Proceedings

An interactive visual decision support tool for sustainable urban river corridor management

Lewis Gill[1], Vikas Kumar[3], Eckart Lange[2], David Lerner[3,] Ed Morgan[2], Daniela Romano[1], Ed Shaw[3]

(acp08lrg, vikas.kumar, e.lange, ed.morgan, d.n.lerner ed.shaw, d.romano)@sheffield.ac.uk

The University of Sheffield

[1] Department of Computer Science, Regent Court, 211 Portobello, Sheffield, S1 4DP, UK
[2] Department of Landscape, Crookesmoor Building, Conduit Road, Sheffield, S10 1FL, UK
[3] Catchment Science Centre, Kroto Research Institute, Broad Lane, Sheffield, S3 7HQ

Abstract: Sustainable integrated catchment management is a complex task that often involves finding compromise between the views of multiple stakeholders that may not easily be brought to consensus. Interactive three dimensional (3D) visualisations of landscapes can facilitate discussion, but these can only partially inform decision makers as many important aspects of interventions are abstract. Such abstract criteria however can be modelled using a Bayesian Network (BN), combining expert opinions, empirical evidence and data derived from existing models. Thus, it is hypothesised that by combining an interactive 3D landscape design software with a BN, a decision support tool is created that brings together the complementary strengths of both techniques. To test this idea, such a tool has been developed for a river management problem in Sheffield, UK. Impounding the River Don that flows through the city are many weirs which form significant landmarks of the urban riverscape and determine the recreational quality for canoeists. Consequently, management decisions must account for the effect of weir modification not only on the visual aesthetic, but also on the abstract recreational quality of the river for canoeists. To support this problem, an interactive tool has been developed that integrates 3D design and visualisation of weir modification options with indicators of the utility of the river from the perspective of the canoeists, modelled using a BN. It is demonstrated that it is possible to feed back the indicator assessment of a design alongside the visualisation or as part the visualisation.

Keywords: Bayesian Network; Decision-support; Integrated catchment management; Weir; Modelling; Interactive 3D landscape; Design process;

1. INTRODUCTION

Sustainable management of urban river corridors is a complex task that, increasingly, involves finding a compromise between the views of multiple stakeholders that may not easily be brought to consensus. One promising method of facilitating discussion between interested parties is to provide interactive three dimensional (3D) visualisations of landscapes, where the viewer is able to move freely around the model (Schroth 2007). When viewing visualisations, people bring their education, experience and interests, each interpreting them from a different viewpoint (Zlatanova 2007). Despite these varied stances, Al-Kodmany (1999) observed stakeholders in collaborative design workshops used digital landscape visualisations as a common language to discuss change. He also found that proposed management interventions can be presented as changes in the virtual landscape, enhancing stakeholder understanding.

Yet, visualisation media alone can only inform decision makers about the spatial and aesthetic nature of management changes. There are many other important non-visual outcomes to a management intervention that the decision maker would like to understand. Logically, the next step is to link visualisation media with modelling techniques that can predict these outcomes, allowing users to more deeply evaluate management interventions. For example, Bishop (2005) proposed an interactive visualisation system for forest management that worked over time and allowed a user to see design changes by moving sliders related to the three pillars of sustainability. Isaacs et al. (2008) showed, using their S-City VT tool, it is possible to show the results of sustainability assessment of built form, modelled with an analytical network process, directly in the 3D visualisation. Gill et al. (2010) suggest constructing interactive 3D landscape models directly connected with assessment models through a defined semantic for areas of landscape using procedural modelling. This allows modelling alterations to directly feed into linked assessments and back to the user in real-time, increasing user understanding of design change.

However, some outcomes of management interventions are more abstract or intricate in nature, proving harder to capture than simple data driven models, and as a consequence new predictive models are now being developing to help address these challenges. Within the uncertain and complex decision problem of integrated catchment management, an increasingly recognised modelling solution is that of the Bayesian Network (BN) (Castelletti & Soncini-Sessa 2007). BNs allow for causal relationships (probabilities) to be specified based on subjective assessments ("expert opinion"), empirical evidence, data derived from existing models, or a combination of all three, making them particularly suitable for integrating predictive information from multiple disciplines (Kumar et al. 2010). Incorporating expert opinion is important because, as is often the case in integrated catchment management, domain expert opinion can be used to create Bayesian networks when there is a paucity of data. However, while increasingly sophisticated modelling techniques are being developed, a barrier to their uptake by water managers is their complexity, and lack of a user friendly interface (Borowski & Hare, 2007). Water managers, who often need to involve stakeholders in the decision making process, do not have time to teach the public to interact with complex models to explore different management options.

Therefore, it is hypothesised that, by combining an interactive 3D landscape design software tool with a BN, a decision support tool can be created that brings together the complementary strengths of both techniques; aiding the understanding of the visual nature of proposed interventions, and making it possible to assess their impact on abstract non-visual criteria. Proposals for changes to river corridors can be fed into the system via user alterations to a 3D landscape model and these alterations can be assessed utilising the knowledge of experts captured in the BN. The overall effect will be that the users of such a system will have an accessible method for increasing their understanding of the consequences of a design decision without the need for extensive training and, thereby, the transfer of knowledge from expert to user will strengthen the process of decision making, as shown in Figure 1.

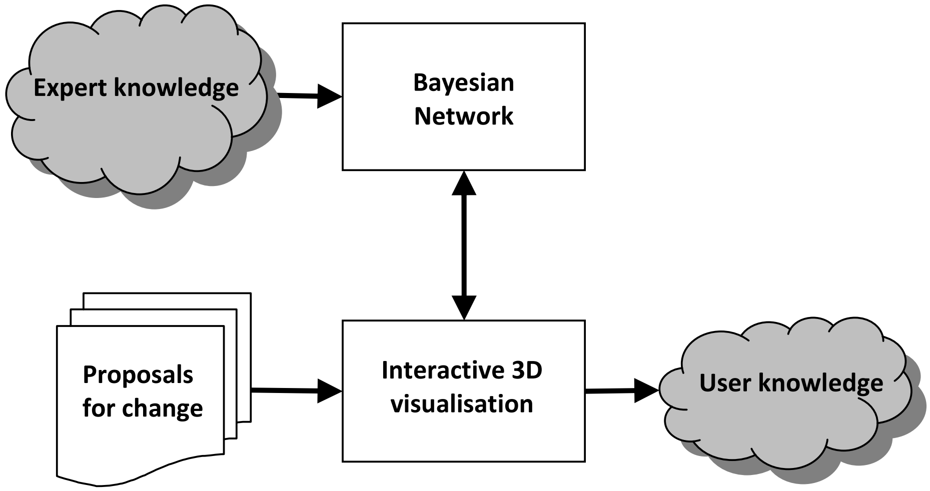

Figure 1. Conceptual model of linking BN to interactive 3D visualisations

In this paper, ongoing work to test this hypothesis is introduced. Work to marry visualisation software to a BN, which tackles a real life catchment management problem, is discussed and future research directions expanded upon.

2. CASE STUDY

In Sheffield, UK, many weirs impound the River Don as it runs through the city. While their primary role as infrastructure for the water wheels of early industry is now obsolete, they are significant landmarks of the urban riverscape. Currently, there is much interest from numerous stakeholder groups in modifying these weirs: some anglers would like to install fish passes; potential victims of flooding are interested in removing weirs; proponents of hydro-electricity want to install micro-hydro schemes; enthusiasts of natural history aspire to restore the river to a more natural state while enthusiasts of the river's heritage want to conserve weirs for their historic value. These modifications also determine the recreational quality of the river for canoeing, a major leisure activity on the river. Weir height, steepness, roughness, plane (orientation relative to the river bank), and presence/absence of attached modifications all determine how canoeists perceive the fun and danger of the weirs. Consequently, decisions on modifying the weirs must account for this abstract impact on the recreational quality of the river for canoeists. To allow this impact to be considered in decision making, an indicator was constructed by building a BN that can predict the influence of weir modification on the quality of the river for canoeing. The process of building this BN and issues regarding its construction are detailed in Shaw et al. (2010).

3. METHOD

To support the testing of the proposed integrated interactive 3D / BN system, a software tool has been developed that presents a graphical view of weir modification options and evaluates the utility of a weir from the perspective of the canoeists. The overall solution comprises of three distinct components: a 3D weir model generator; an assessment system containing the BN and an interactive 3D visualisation system. Miller (1968) states that there can be a detrimental effect on the train of thought of a user when a computer system response to user input is greater than one second. Therefore, to avoid hindering the design process taking place, it is aimed to make the integrated system react at within this time frame, whilst attempting to deliver output in real-time to provide an interactive experience.

3.1 3D weir model generator

The role of this component is to procedurally generate 3D models of weirs, which increases the speed of generating models of the weirs and removes the need to manually construct models. The generator needs several inputs; a 2D polygon region that defines the extent of the weir, two independent edges along the polygon that define the upstream and downstream boundaries, and a distinct set of parameters that allow the user to implement various weir management options. The polygon area of the weir can often be derived from geographic map data, such as the Ordnance Survey Mastermap data. The parameters are simple name/value pairs, such as weir 'Height', 'Bumpiness', 'Number of Steps' in the weir. Given these inputs, the system generates a 3D representation of the weir using the base polygon and parameters to inform the shape of the resultant model. If the weir polygon is altered or the attributes changes, the system will remove the existing model and replace it with one that incorporates the alterations upon a user request for an updated model.

3.2 Assessment system

The canoeist BN, referred to Section 2, has been developed using the Netica software package that allows a BN to be defined using a standard graphical user interface. Each variable (node) in the Netica model has a series of discrete states, e.g. weir height is categorised as 'High' (>3m), 'Medium' (1-3m) and 'Low' (<1m). The nodes are linked in a cause-effect network and the relationships between them are described probabilistically. At the end of the network are indicator nodes; danger and fun of a weir from the viewpoint of canoeists and river quality a combined function of the danger and fun. When the state of an input parameter is set, probabilities will propagate through the BN changing the states of the indicator variables. The compiled Netica model is then linked to the 3D weir model generator through the use of the Netica Application Programming Interface (API). One advantage of using this API is that the system maintains a separation of the BN from the visualisation system and 3D model generator, which allows refinements to be made to the BN outside the visualisation host program, but feed directly into the model assessments.

As a weir model is generated, the various key/value parameters are fed into a weir assessment module in the form of input variables. Additionally, the geometry of the input polygon is analysed to determine the following extra parameters; width, steepness, and weir plane, and these are also fed into the assessment system. Once the input values are assigned to the nodes in the BN, the assessment system can then interrogate other BN nodes to retrieve the altered indicator values, which are then available to be displayed to the user.

The assessment system is designed to incorporate multiple assessment models at once and provide an overall assessment based on all connected models. The BN is integrated alongside a more traditional data and process driven model that examines the potential for hydro-electric power generation. This model, created in Excel, is integrated with the assessment system through COM automation. In a similar fashion to the BN integration, appropriate inputs are fed directly into the Excel model and cell values are available to read back to the assessment system.

Results of the multiple assessments can then be displayed either in a separate window, or within the visualisation, depending on suitability. The system outputs the results of assessments in HTML, which provides the basis for a highly configurable output to the user. So far, the system displays the predicted states for indicator nodes in the Netica model and outputs one result of the micro-hydro model as proof of concept.

The 3D model generator is connected to the assessment system and, when a model is created, it forces an assessment be made. The model generator compiles a list of all the variables needed and passes these, as required, to each analytical model in the assessment system. When inputs alter, it is the assessment system that is responsible for displaying the resultant indicator values to the user. This ensures that when a model is altered an up to date assessment is presented to the user. As the model generator issues the assessment, it can incorporate the results of the analysis in the resultant model. For instance, the model can be coloured to display the level of weir "fun" derived from the BN to give visual feedback within the visualisation. A threshold value of 40% certainty being reached in either the "high" or "low" states results in the model being coloured green or red respectively, otherwise it is assumed to be in an intermediate state and coloured gray.

3.3 Interactive 3D visualisation system

The weir generator and assessment system have been created in C++ allowing them to be used in a "plug-in" module for the interactive 3D landscape visualisation system, Simmetry3d , which is based on video game technologies. This enables users to make weir modifications within larger landscape visualisations that provide spatial context. Simmetry3d offers interactive views both in birds-eye and eye level "walk-throughs" on a range of computer hardware, from laptops to immersive stereo projection, giving flexibility when supporting stakeholder workshops.

To model a weir in Simmetry3d, all the user needs do is create a weir polygon in the model using the polyline tool, and designate this as a weir area. The upstream and downstream edges have to be selected and the input parameters dialog is displayed, so the user can begin modelling.

4. RESULTS

The various components of the system detailed in the previous section are functional, linked together within Simmetry3d and respond interactively within the Miller time metric. Users can make weir modifications by changing parameters in a window that appears alongside the visualisation, as shown in Figure 2.

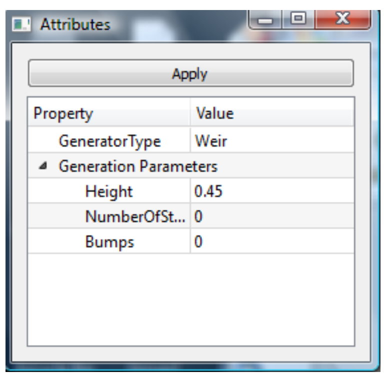

Figure 2. Weir modification parameter dialog

By altering these and pressing an "apply" button, a weir model is generated for the user. In Figure 3, two different weir modification options are visualised, separated for clarity from a larger landscape model. The first option shows a weir with a specified height of 1.4m, and the model shows a green colour to indicate a "high" level of "fun" for canoeists. The assessment window to the right shows the BN output for the overall quality of the stretch of river by the weir for canoeists, and the number of people the electricity generated by a micro-hydro scheme could provide for. The second option shows a weir with a specified height of 0.4m and a stepped profile with the red colour indicating it offers a "low" level of "fun". The second assessment shows little alteration to the river quality for canoeists (as the BN still needs further refinement), but a marked reduction in potential micro-hydro output.

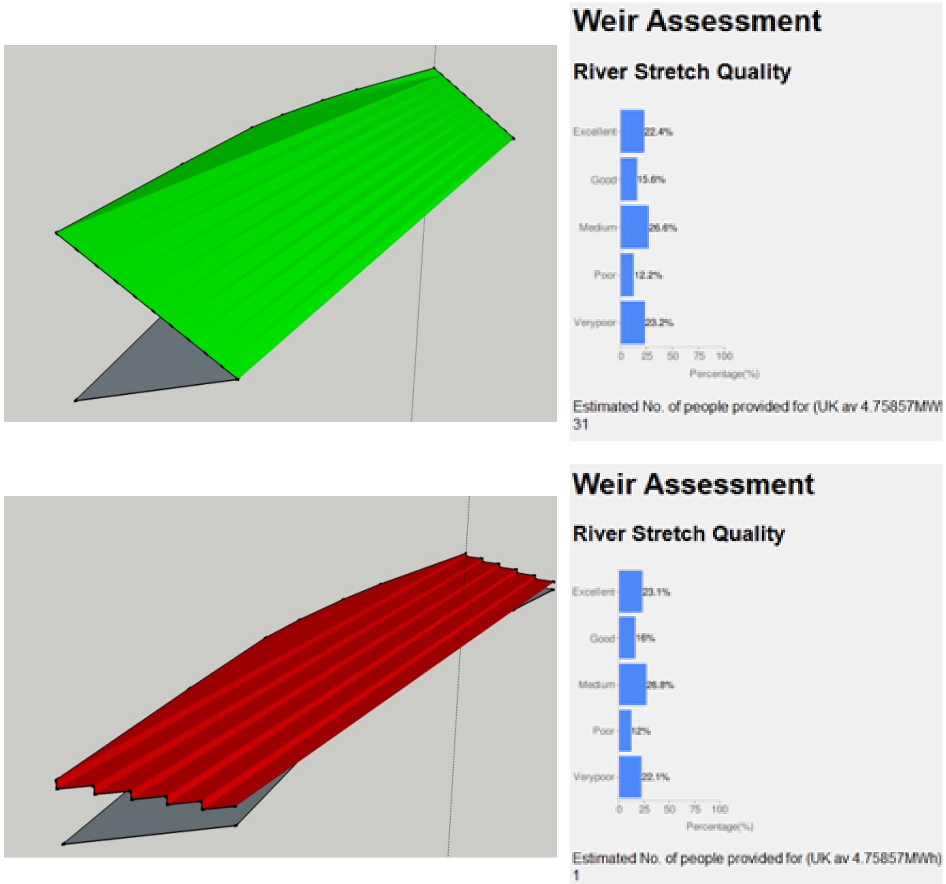

Figure 3. Two weir modification options for a weir modelled in 3D with their assessments

The weir modification system has also been placed into a larger landscape model (Figure 4) that allows the landscape context to be understood as the weir is altered. This model is demonstrating the use of a more realistic textured surface rather than representing the "fun" factor of the weir.

#

Figure 4. Interactive weir model in context within a larger existing landscape model

5. DISCUSSION & CONCLUSION

Whilst much progress has already been made on the weir modelling tool, at the time of writing there are several key features that still need to be added before user testing is possible. These include modelling the placement and effect of fish / canoe passes in the 3D weir model and allowing changes made in the 3D visualisation to feed back to the associated parameters. The assessment system will also be extended to include a model that determines the effect of weir modifications on the critically endangered European Eel (*Anguilla anguilla*), providing an ecological indicator of design quality, and a cost model providing an economic indicator. Further work will take place to enhance the amount of information available to the user in the assessment window. With catchment wide processes affected by weir modification (e.g. eel migration), it is anticipated that the modelling tool will be extended to allow views of connected weirs within a catchment giving the user ability to test different weir modifications more strategically.

This research is part of the Urban River corridors and Sustainable Living Agendas (URSULA) project, which is conducting interdisciplinary research into the multifaceted problem of creating sustainable urban riverside landscapes. In the longer term, it is envisioned that the prototype weir design tool will provide the foundations for a more extensive system that will incorporate the future research outputs from URSULA into a more complex BN, allowing the visualisation and interactive modelling of more aspects of the riverscape, whilst providing an integrated assessment of these alterations.

ACKNOWLEDGEMENTS

This paper is based on work undertaken within the URSULA project, funded by the UK Engineering and Physical Sciences Research Council (Grant number: EP/F007388/1). The authors are grateful for this support, but they would like to note that the views presented in the paper are those of the authors and cannot be taken as indicative in any way of the position of the funders or of colleagues and partners. Any remaining errors are similarly those of the authors alone.

REFERENCES

Al-Kodmany, K., Using visualization techniques for enhancing public participation in planning and design: process, implementation, and evaluation. *Landscape and Urban Planning,* 45(1), 37-45, 1999.

Bishop, I.D., Visualization for participation: the advantages of realtime, Trends in Real-Time Landscape Visualisation and Participation Proceedings at Anhalt University of Applied Sciences, E. Buhmann, P. Paar, I. D. Bishop, and E. Lange, eds., Berlin: Wichmann, 2–15, 2005.

Borowski, I. and M. Hare, Exploring the Gap Between Water Managers and Researchers: Difficulties of Model-Based Tools to Support Practical Water Management. *Water Resources Management*, 21, 1049-1074, 2007.

Castelletti, A., and R. Soncini-Sessa, Bayesian networks in water resource modelling and management. *Environmental Modelling and Software, 22*, 1073-1074, 2007.

Gill L., E. Lange, E. Morgan and D. Romano, Interactive 3D landscape assessment models. Proceedings of Digital Landscape Architecture 2010, May 27 – 29, Anhalt University of Applied Sciences, Aschersleben, 2010.

Isaacs, J., R. Falconer, and D. Blackwood, A Unique Approach to Visualising Sustainability in the Built Environment. In Proceedings of the 2008 International Conference Visualisation, IEEE Computer Society Press Los Alamitos, CA, USA, pp. 3-10, 2008.

Kumar, V., A. Holzkaemper, and D.N. Lerner, Integrated Meta-Modelling for Decision Support in Integrated Catchment Management. iEMSs, Ottawa, 2010.

Miller, R.B., Response time in man-computer conversational transactions. In Proceedings of the fall joint computer conference, part I. December 9-11, San Francisco, California: ACM, pp. 267-277, 1968.

Schroth, O., From Information to Participation - Interactive Landscape Visualization as a Tool for Collaborative Planning. Dissertation No. 17409. ETH Zürich, 2007.

Shaw, E.A., V. Kumar, D.N. Lerner, and E. Lange. Bayesian Belief Networks and Social Objectives: A Canoeing Case Study. iEMSs, Ottawa, 2010.

Zlatanova, S., M. Dorst, and L. Itard, The role of visual information in design tools for urban renewal, W21, Rotterdam, Netherlands, 2007.