A REVIEW AND COMPARISON OF DATA VISUALIZATION TECHNIQUES USED IN BUILDING DESIGN AND IN BUILDING SIMULATION

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ABSTRACT

This paper will present a review, for a range of building design and performance issues, of the visualization language used in building design and in building simulation, and identify the overlaps and divergences in their use. There is a plethora of techniques available ranging from textual data to graphical representation, from 2D drawings to 3D representations, and from static images to interactive animations and virtual reality. The review has been undertaken using taxonomy of visualization techniques based on data type and analytic task. The review and classification of available techniques also enables a comparative study of the various ways to visualize specific data and thus, attempts to identify the most effective visualization technique for different analyses aimed at the design community as users. The results are used to propose a new interface "look and feel" for early-stage design analysis software.

INTRODUCTION

Visualization has been used to interpret data through maps and diagrams from as early as 1137 in China (Brown Judith R., 1995). Since then, there has been immense development in use of and techniques for visualization in all fields. In architecture, it has been of particular assistance to visualize and convey ideas and to analyse information and data. Visual representation has been instrumental as an aid to analysis of factors influencing building design. Their applicability has been further reinforced with the advent of computer simulation and analysis. T. Hong et al. (2000) provide a broad classification of computer based tools in building design into CAD design and drafting and computer based simulation.

The transfer of visualization techniques used for representation of the building form in plans, sections, details, perspectives etc. from the traditional manual methods to the computer processing has been smooth and consistent with the same graphic technique and presentation being used. However, the same cannot be said for techniques of analysis. Analysis has been an integral part of the building design process. The process incorporates the need for site analysis at the very outset. This is followed by a comparative analysis of various design options aesthetically, functionally, economically and more recently on the basis of environmental performance. The visual aids used for such analytical tasks in the computer world have not been translated in concurrence with the existent norms of the design realm. Although there are a number of analytic task that have become possible only recently with the aid of computer simulation, there is a clear loss of congruity in the visualization techniques used for analyses in traditional design and modern simulation. This variance has been felt by the professionals and can be noticed in the reluctance to the use of computer simulations despite their noted advantages. While the use of CAD and 3D for envisioning design has been taken up extremely rapidly by professional around the world (Hong T. et al., 2000); the use of simulation tools is yet to see such an expansion. One of the major reasons for this is the lack of appropriate visualization methodologies in the said tools.

As such, there originates a need for redressing the visualization techniques used in simulation programs to satisfy the needs of the design professionals. This has been emphasized in many studies on the use of simulation programs. For instance, the concluding remarks for a study on 'A Survey of Users of Thermal Simulation Programs' bring forth the following remarks-

Tools to ensure that the relationship between data input and performance can be studied systematically;

Tools to permit the communication of the building performance to clients. (Donn M. R., 1997)

A review of currently prevalent norms in visualization in building design and building simulation is hereby presented to illustrate the overlaps and divergence in techniques.

A quick look (Table 1) at the two classification types mentioned above shows some of the very basic differences in the visualization techniques. Whilst for representing design data, we use information visualization with the help of drawings and diagrams and the data is mostly spatial or conceptual, for the analysis of simulation results, we need scientific visualization techniques, including graphs, charts and the like. Moreover, the data is often spatiotemporal (3d spatial component with temporal dimension), which is one of the key impediments to good visualization techniques.

Table 1
Basic differences between design and simulation visualization

Design	Simulation
Information Visualization	Scientific Visualization
Qualitative	Quantitative
Sketch/Drawing/Diagram	Graphics
Spatial(3D)	Spatiotemporal(4D)
Conceptual	Empirical

DESIGN VISUALIZATION

A synopsis of the visualization techniques used for design drafting and presentation shows that the advent of Computer Aided Design and presentation has not only increased the productivity of the design community but given them a valuable resource for producing excellent visuals. It has also led to a great deal of flexibility in exploring various design options by making quick changes possible and increased the interactivity through 3D modelling. As mentioned earlier, the apparent advantages have led to the extensive use of CAD by building professional.

It must be noted, however, that most successful computer tools would seem to be those which have adopted (and adapted) the look and feel of the manual methods with ease of use.

Figure 1 represents the various manual and computer aided methods of data visualization in building design and it can be seen that the computer aided methods successfully emulate the manual methods of visualization and enhance them.

The consistency of visual representation can be

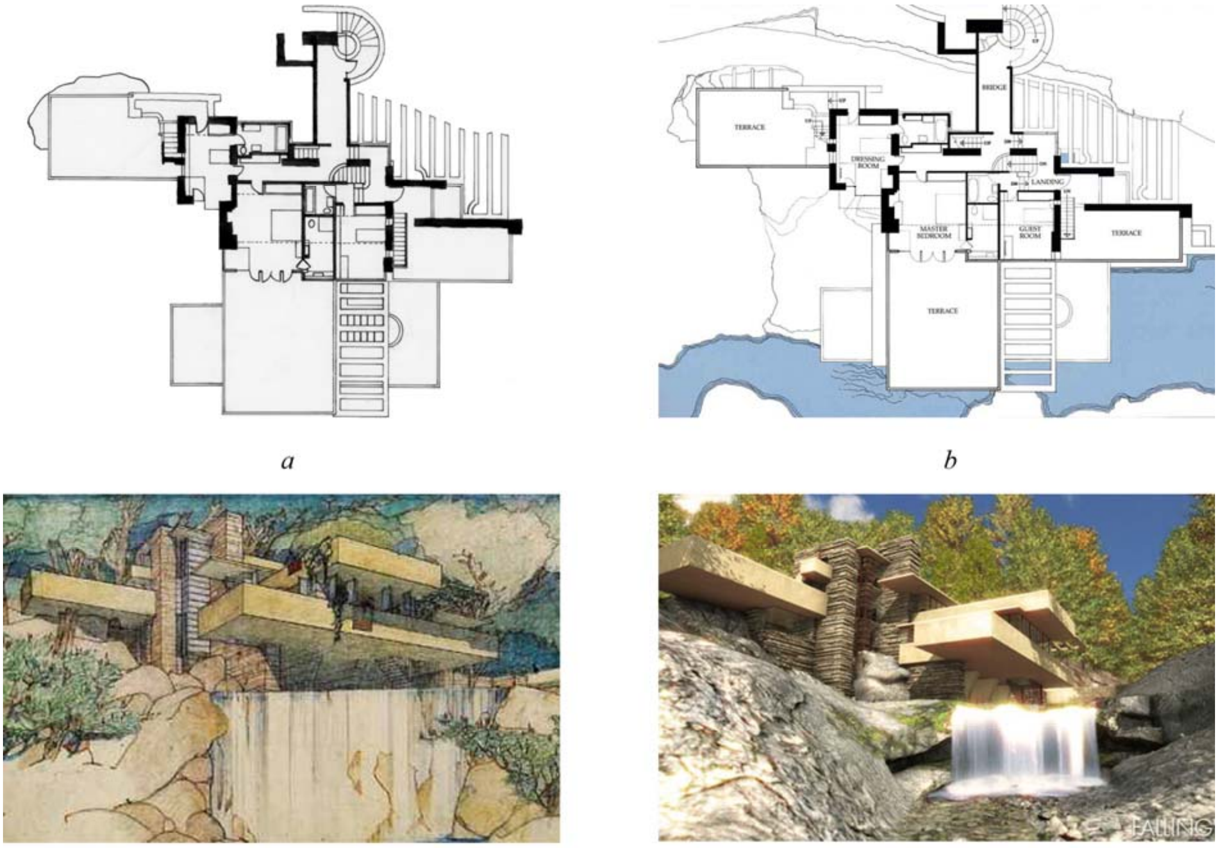


Figure 1 Manual and Computer Visualisation in Design

clearly seen in both methods at all levels of design illustration from plans, to section and elevation. It can also be inferred that the use of computers has significantly enhanced the 3D visualization technique by the use of virtual modelling and animation. Not only does it help the designer to envisage his vision as a whole, it provides an excellent medium for the transfer of knowledge between stakeholders as mentioned earlier. A 3D representation is one of the easiest ways to present a design to a client and using this medium for illustrating numerous design options was not feasible using physical models and perspectives due to restraints of time and resources. But the advent of computer modelling has made it easy and viable to do so.

3D modelling and animation are now among the most popular presentation tools among designers worldwide to present their design to other stakeholders, especially clients. Advances in Virtual reality are set to make design visualization more realistic by providing a medium to experience space in 3D.

It can be said then that design visualization in computer and manual methods is analogous. As such this paper will now focus on simulation visualization where a lot more divergence in the visual language is noticeable.

It is essential to note here, that even though the use of CAD has been widespread, it is still not used even for the most basic analyses i.e. the site analysis. Thus, despite the fact that site analysis is an integral part of the building concept and design, it has been classified in this study among the simulation and analyses.

SIMULATION VISUALIZATION

Simulation visualization in building design can be categorised into site analysis and building performance simulation based on differences in data type and analysis. With in site analysis, visual representations are needed for the existing conditions on site in terms of topography, solar access, overshadowing, wind conditions, climatic conditions and potential noise problems.

Building professionals have traditionally depended on ‘rule of thumb’ and ‘experience’ for such analysis with visuals tools being used only for presentation. Most of these analyses were done with sketch diagrams, the climate data studied from tables and charts, the wind simulated in wind tunnels and solar analysis performed in sky domes. For the majority of the projects the use of wind tunnels or sky domes was not feasible and hence the analyses were limited to ‘rule of thumb’ assumptions.

With the use of computers, however, we have a whole new world of analysis tools that can help us study the site in all its complexity and detail. Yet, the use of computer tools for site analysis is very limited. One of the reasons for this would seem to be the divergence of visualization techniques in the traditional analyses and those used in computer analysis. As has been seen from the experience of design visualization, the most successful tools tend to be those that have adapted the look and feel of the manual methods. It can be seen from the array of techniques used for site analysis, that some of the parameters have been adapted in computer visualization from the manual methods. For instance, topography visualization is much the same as manual methods and further improved to present a realistic view of the terrain. The climate data overview is also well translated in the weather data visualization software’s. But when it comes to the microclimate analysis, designers still depend on manually drawn concept sketches.

As seen in Figure 2(a), the method of site analysis used by architects comprises of sketchy overview of climate conditions on site and is often extended to include views, access etc. The manual presentation effectively uses layering, colour coding, varying line thickness etc. to present a multitude of data on the same drawing. Digital methods (Figure 2(b)) on the other hand, provide very good detailed wind/solar analysis but fail to coherently present the climate data on site in a format that is easily comprehensible. The potential of computer simulation for analysing the microclimate is not being tapped effectively owing to presentation variance.

That being the case with site analysis, the case of building performance simulation is different. There being no or little precedent for many such analyses in the traditional methods apart from ‘rule of thumb’ and ‘experience’, it would seem that the visual techniques used in such software should become convention. Yet, the use of simulation software’s is not so common and one of the major reasons for such a hurdle in their widespread use is visualization. The reason here, for the apparent failure of currently employed visualization techniques, is the complexity of the data to be analysed. As Laiserin has pointed out, “Because the results are so difficult to interpret from numerical answers alone architects and engineers increasingly turn to visualizations. Whether in 2D or 3D, still images or animation, such visualizations play an

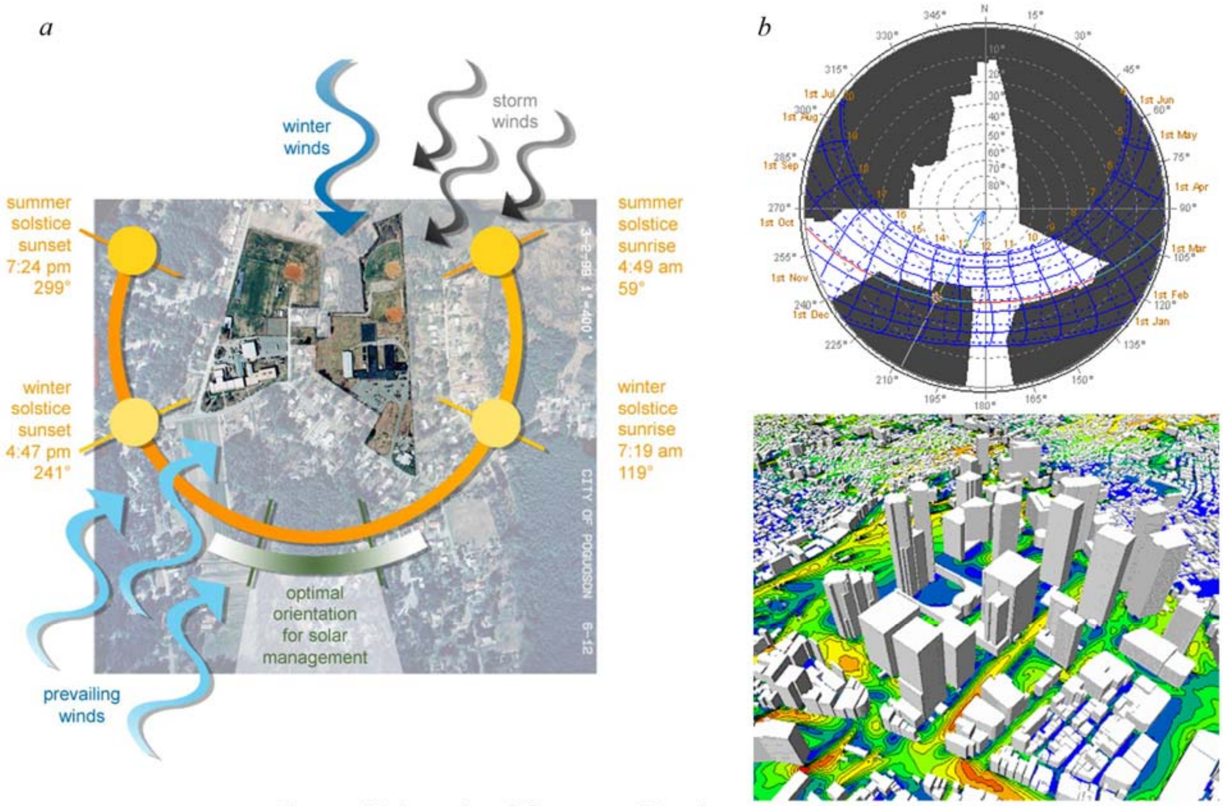


Figure 2 Manual and Computer Visualisation in Simulation

increasingly important role in helping to predict, identify and correct potential trouble spots in building performance prior to construction." (Laiserin J. 2001)

Currently, the most prevalent visualization technique for simulation result analysis are 2D graphs, spreadsheets and tables (Pilgrim M. et al, 2003) usually made by using a postprocessor like Excel, which is not customised to the specific need of building simulation data analysis. 'Visualisation of simulation results through a number of graphs may well reduce the richness of the 'integrated' simulation.'(Mourshed et al., 2003)

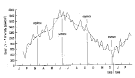
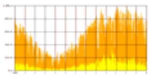
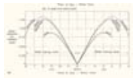
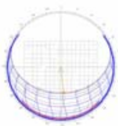
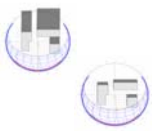
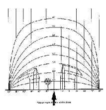
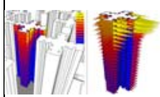
Majority of building simulation data is spatiotemporal and the visualization techniques available to us so far are unable to deal with the complexity. There is a need for a visual aid that can represent spatiotemporal data in a way that makes the relationships and patterns of the 4D data comprehensible to the user. Recent work by Prazeres and Clarke (2005) focuses on various visualisation methods for the 'copious amounts of complex and time-varying data' generated by simulation programs, using interactive graphical, geometrical, alphanumeric, image, and sound data.

Most simulation programs seem to be aimed at engineers and thus focus more on the methodology and accuracy of the results rather than their presentation. This can be corroborated through the vast number of publications on new tools that fail to address the issue of visualisation with the focus it needs (see –Yan and Jiang, 2005 and Crawley et al., 2000). There have been a few attempts in tools to make them more perceptive to the design community. For example, ECOTECT (Marsh, 1996) is aimed at the design community and features some novel visualisation techniques for presenting lighting and acoustic data. ECOTECT features a more designer oriented interface as compared to Energy Plus or IES, but it follows the same graphical presentation techniques for energy. Also, most of these programs focus on the performance of a single case using numerical indicators of performance. For a designer, the quantitative data holds less importance than the ability to visualise the qualitative effect of various design strategies, thus, raising the need of comparative indicators for a number of cases. However, these tools fail to comprehensively focus on the early stage site analysis which is the focus of this paper.

SIMULATION VISUALIZATION ANALYSIS

To further examine the available and potential visualization techniques in building data analysis, in particular the elements common to site analysis and building performance simulation for e.g. Solar access – Day lighting (Table 2) is studied within a framework of visualization taxonomy. Solar analysis has been used as exemplar here since it forms part of site analysis and building simulation is based on the fact that it is one of the most crucial elements to be considered before and during design in order to promote sustainable and energy efficient design. It also has a cascading impact on energy and renewable potential. Solar access study on site provides guidelines for building position, orientation and fenestration design helping minimize/maximize solar gains and maximize daylight in the building as well as providing data for feasibility of solar renewable technologies on site. This influences the energy use in building and energy supply. Likewise, Wind analysis on site helps designers orient the buildings to benefit from the prevailing wind conditions and CFD analysis around and inside the building helps ensures pedestrian and occupant comfort. There has been a lot of focus on the presentation techniques used for day lighting analysis and CFD within buildings and it can be seen from the example in Table 2 that despite the complexity of the data to be presented, the visualisation used is highly perceptive for the user. There is still scope for improvement on these visual techniques; for example, they still lack the ability to present the 4D data comprehensibly to bring out the patterns of performance. The visualisation of solar access on site however, is not so well developed. The techniques used here are more difficult to perceive since they are based on scientific visualisation using graphs like sun-path and waldrum diagram and skydomes.

Table 2
Taxonomical Review of Site Analysis Visualisation (Solar Access/OverShadowing)

	Overview		Comparison		Distribution Pattern	
	Manual	Computer	Manual	Computer	Manual	Computer
1D						
2D						
3D						
Multi - Dimensional						

The taxonomy used for this classification of techniques has been adapted from a user oriented framework proposed by Chengzhi Qin et al (2003). The framework presents taxonomy of visualization techniques based on data type and the analytic task. Being a user oriented framework, this taxonomy will help understand the user's perspective for choosing visualization techniques as against a software developer's, thus helping identify the variance in client expectation and current norm. Moreover, classifying the visual techniques by analytic task, various visual methods for representing the same data can be identified. This provides users options to choose the appropriate visualization method to suit their analysis needs.

In the proposed framework, Chengzhi et al (2003) have identified five classes of analytic task namely, overview, comparison, cluster classification, distribution pattern and dependency correlation analysis. When considering site analysis and building performance simulation, this can be narrowed down to three classes – overview, comparison and distribution pattern.

Table 2 illustrates the classification of solar access and overshadowing analysis as per the proposed taxonomy. It also acts as a guide for choosing the right visualization for comparisons like the summer winter case or the distribution pattern for sky view or overshadowing at different times of the day. For instance, if the analysis requires a comparison of summer and winter shadow patterns, the use of computer models that generate shadows as per sun position on the sun path are very useful. Or if the analysis involves an overview, the user may find the manual representation or sun path most useful.

Data dimensionality is also an important aspect to consider when designing visualization. In building data analysis, there are a number of data types. For example, topography is spatial data (3D) and can be represented as point heights (1D), contours (2D), or extruded contour/ 3D surface (3D). In the absence of computer modelling tools, it was essential to simplify the data into 1D and 2D forms to represent it on paper, 3D physical models/perspective views were sometimes made, but with computer modelling it has become easier and viable to visualize topography through virtual 3D models. Data dimensionality acquires a more critical form when dealing with building analysis data with a temporal component.

Fundamentally, a lot of analysis data has both spatial as well as temporal dimension. This presents us with 4D data, techniques for visualising which are limited. Much of analysis data, like lighting, CFD, noise and thermal comfort is distributed in 3D space and varies with time. Currently such data is simplified to 2D spatial component with temporal dimension, or 3D space in static state (fixed moment in time). Such visualization is, no doubt, extremely useful in studying the details of the analysis but an overview of the data in its entirety will also be useful to determine patterns. Animation and virtual reality are the likely visualization techniques that can deal with such complex data, and as was identified by Pilgrim et al., these were chosen by the design community as the future techniques with most potential (Pilgrim M. et al, 2003). While these techniques are still in developing stages, attempts can be made to increase congruity in the manual and computer presentation in terms of analysis data to make it more perceptible to designers and clients alike. A conscious attempt to de-engineer the visualisation of results in building simulation softwares will ensure higher uptake of such software by designers and thus help spread sustainable design ideals.

CONCLUSION

It can be summarised then that among the currently prevailing norms of visualization in the building industry design visualization has followed a seamless transition from manual to digital methods and is being widely used. Against this, visual methods for the simulation and analyses in building design are yet to see such expansion, despite the noted advantages of using computer tools.

There is an immediate need to further investigate the existing methods of visualization as well as develop new methods that effectively represent multidimensional data, are easy to understand and can be used to communicate simulation data among various stakeholders in the design team. The essentials for good data visualization for simulation and analyses can be concluded as follows-

- The visualization strategy should derive from manual methods where possible to help designers make a transition from their current practice.
- It should have the ability to represent multidimensional data.
- It must be interactive and allow effective communication between stakeholders from varying backgrounds.
- As noted by Ormerod and Aouad (1997), ‘there must be a balance between complexity and novelty in images providing the interpreter with sufficient stimulus but not overload their perceptive system’.

There is another important consideration when developing visualization techniques. In the traditional methods of analysis, when designers used physical models for solar, wind or other analysis, they had a more interactive relationship with the model and as such better understood the cause and effect relationships that shape the results. Automated computer modelling often skips over the computation core to present results which means, the designers may or may not fully understand the implications of their actions. As such, it is essential not to loose the link with the process in visualising analysis data so as to help the designers be fully aware of the cause-affect relationships of their interventions.

An attempt to interpret the manual visualisation of site analysis, using more complex and well developed computer analysis techniques, has been made to inform the visualisation of site analysis in an early stage design tool called ClimateLite (Figure 3). It aims at converging the visual languages in manual and computer analysis methods where precedents of traditional visualization techniques exist. It follows a system of layering data, for instance, layers of qualitative data like roads, trees, water features etc. and also layers of quantitative data like overshadowing, noise intensity map, wind profile etc. And where such precedents do not exist, i.e. new building simulation methodologies like energy and carbon, an attempt has been made to make the visualization intuitive and interactive in a way that the user understands the process and the results hence derived .

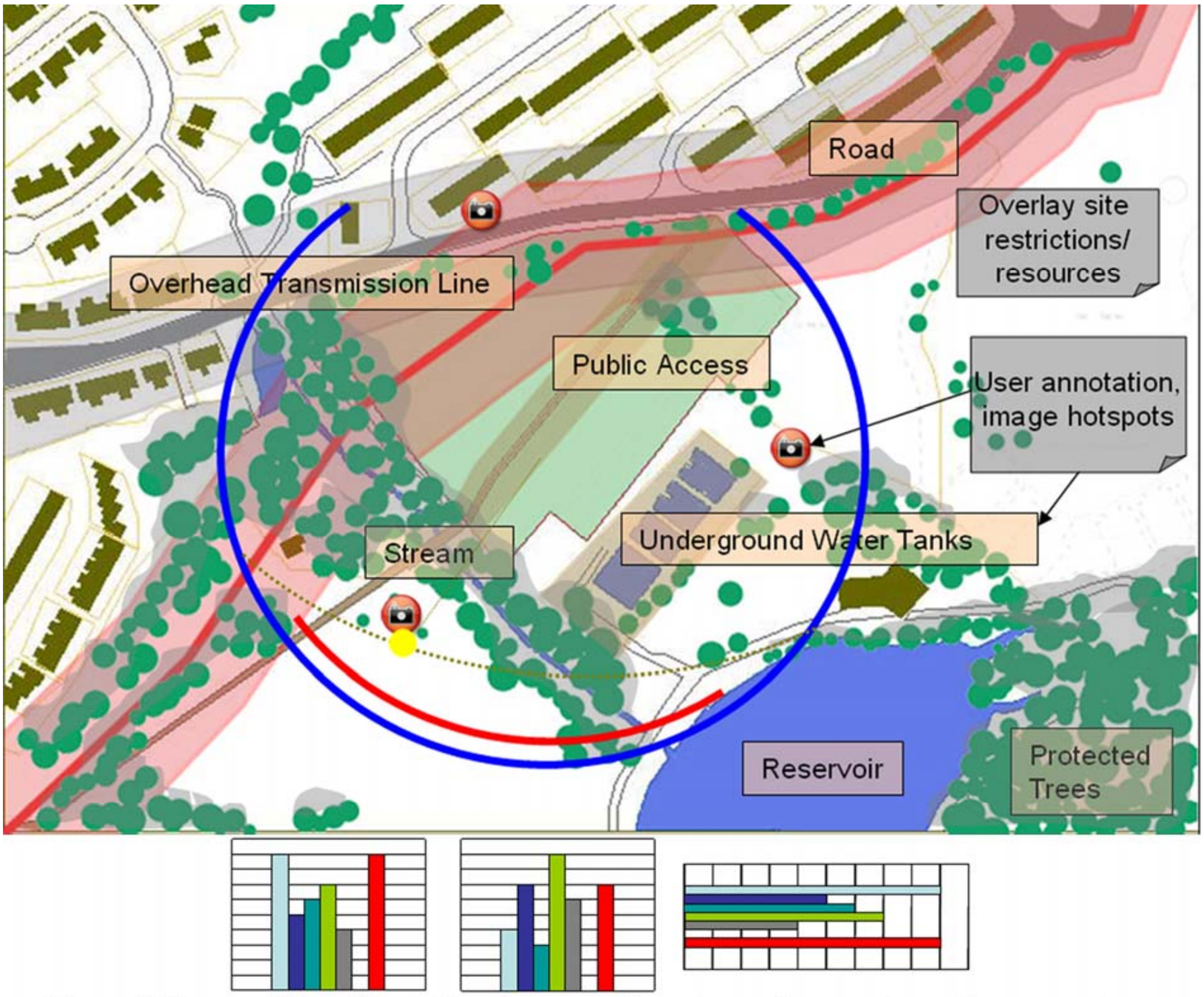


Figure 3 Proposed Interface with information layering and comparison charts prominent rather than numbers

Most of the site analysis data is represented on the drawing using colour coding and layering with the ability of manipulating the visibility of layers as desired by the designers. For quantitative data like energy and carbon, the usual method of engineering displays giving prominence to numbers is avoided. Instead, a system of comparative evaluation is introduced whereby; the designer has the ability to see the effects of design interventions on the energy and carbon, without stressing the actual numerical value but on the comparative advantages/ disadvantages of design options.

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Figure 1(a) Sketch plan – www.decoratingflair.com
Perspective – www.postershop.co.uk
Figure 1(b) Plan – www.wpconline.org
3D image – www.ursispaltenstein.ch
Figure 2(a) Site Analysis – www.designshare.com
Figure 2(b) Overshadowing – www.squ1.org
CFD – www.aij.or.jp