Procession: using intelligent 3d information visualisation to support client understanding during construction projects

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ABSTRACT

The latest results in the development of the software tool 'Procession' are presented. The research underlying Procession delivers a conceptual 3d framework for the interpretation of non-physical construction industry processes. Procession is the implementation of the proposed 3d framework, as an Information visualisation software tool. The conceptual transformation of construction clients' informational needs into 3d visual structures is documented. Also discussed is the development of an 'intelligent' software process to calculate the relevance of individual project elements. This is used to determine the representation of project elements within a 3d data surface. Construction is not short of technologies for visualising physical building models. However, it would seem that little or no consideration has been given to improving the intelligibility of non-physical construction processes. This type of information is usually known as Project Planning data and is concerned with the individual tasks (or processes) that make up construction projects. While, there are software applications that allow access to this data for the professional members of the project team, clients are currently without a suitable tool. Procession's data surface is an abstract representation of three selected project dimensions. Its 3d progress reports provide construction clients with an 'at-a-glance' indication of project 'health'.

Keywords: Abstract non-physical data, 3d, construction industry, client, information visualisation, planning, project management

1. INTRODUCTION

This paper provides a brief report on current progress in the development of 'Procession', an information visualisation software tool for construction project clients. In recent years, debate about information technology in the construction industry has tended to focus on EDI (Electronic Data Interchange) and interoperability (both in terms of software tools and data models). Whilst being valuable, such discussion often neglects the following considerations:

- The interface metaphors underlying construction industry software seem predominantly drawn from architectural rather than project planning paradigms.
- The importance of the construction client as a stakeholder in the project data is often minimised.
- Construction clients are currently without software tools that specifically reflect their informational needs.

Proposals for interoperability often include team members who depend on data concerning the project's 'process' rather than its 'product'. For example, a project manager may need detailed access to the information relating to financial planning and scheduling. Construction clients may have a strong interest in data from the same source but their requirements are less comprehensive. It was recognised that information visualisation could provide clients with a summarised project progress report, simplifying the complexity of the project process. The software tools used by architects and engineers often make use of three dimensional spatialisation to aid product intelligibility. It was realised that informative results might be obtained by applying 3d visualisation technologies to the development of a client reporting tool. In-built Internet functionality was incorporated, enabling clients to obtain progress reports at their convenience.

Information visualisation is a new and rapidly developing field, emerging from the well-established areas of data visualisation and scientific visualisation. Card et al. define information visualisation as, "the use of computer-supported, interactive, visual representations of abstract data to amplify cognition". [1] As a technique, it can be applied to finance, database structure, business processes and project planning. As virtual environments techniques become readily available on a wide range of computer platforms, they are increasingly applied to the interpretation and analysis of multi-dimensional, electronic based information. The primary function of information visualisation is arguably to enhance the intelligibility of complex data sets, by revealing emergent patterns and relationships.

By definition, information visualisation is applied to abstract and generally non-physical data sets. Project process data is abstract in the sense that it is purely numerical and has no intrinsic spatial form. It is possible for abstract data to be represented in conjunction with a physical visual structure. For example, colour scaling might be superimposed on a 3d building model, to represent levels of construction cost. This is a hybrid solution which has not been selected for this research. Instead, an attempt has been made to combine abstract and non-physical visualisation, so that the data can be spatially explored in isolation from its built product.

The results of initial research (see Fig. 1) have crystallised into an initial software prototype, ‘Procession’. Procession's 3d data surface shows the user ‘at-a-glance’ the current ‘health’ of a construction project. A flat terrain indicates that the project is proceeding according to its intended program. Spikes and troughs warn the viewer that deviations have occurred in terms of time, cost and quality. Whilst, there is a body of work concerned with construction process modelling, this has previously tended to investigate the sequential and periodic nature of the project lifecycle, rather than analysing and reporting properties emergent from the process. In the next section, these emergent properties will be considered in more depth.

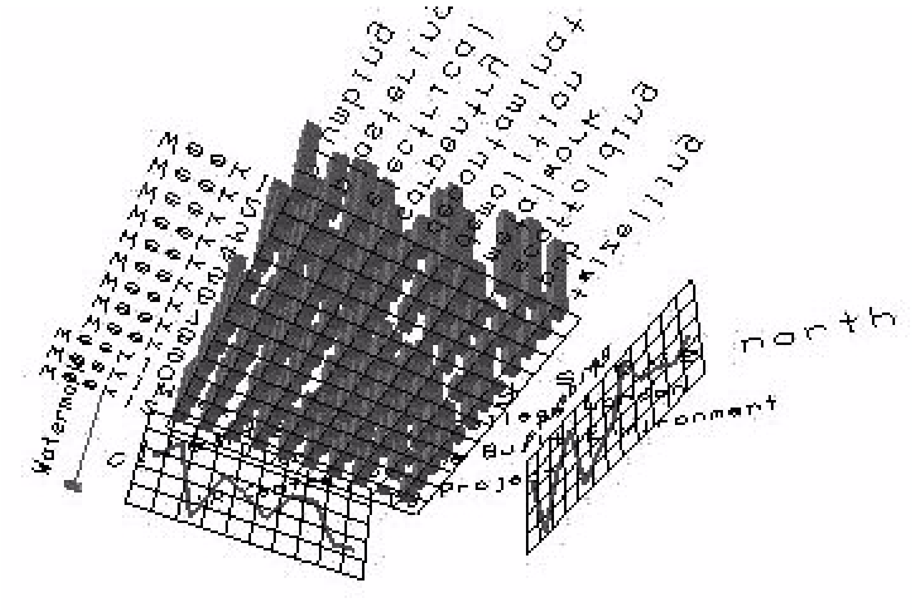

Figure 1. *Early example of a Procession 3d data surface as viewed from below,*source: author.

2. CONSTRUCTION PLANNING DATA

In contrast to product data, ‘process’ or ‘planning’ data does not describe the building itself. For instance, product data might be expected to include the architect’s 3d computer aided design (CAD) models. Rather than looking at the CAD tools currently available to simulate the building itself, this work has considered the development of potentially more intelligible ways to visualise information generated by the project process. The raw data providing a source for Procession, comes from the phase of a construction project where building has actually commenced. This is known as the ‘on-site’ project phase and progress reports at this time, may be of particular value to construction clients. Before starting to build, a ‘baseline’ is usually developed from the project program. This consists of predicted durations and costings for tasks in the project lifecycle. A project baseline builds upon the previous experience of construction project managers to create a plan that represents their expectations for the project. For each project task, the baseline is used to compare the original plan for the project with the actual course of the project. It is possible to see which tasks started earlier or later than planned, exceeded their original budget, took longer than planned, and so on.

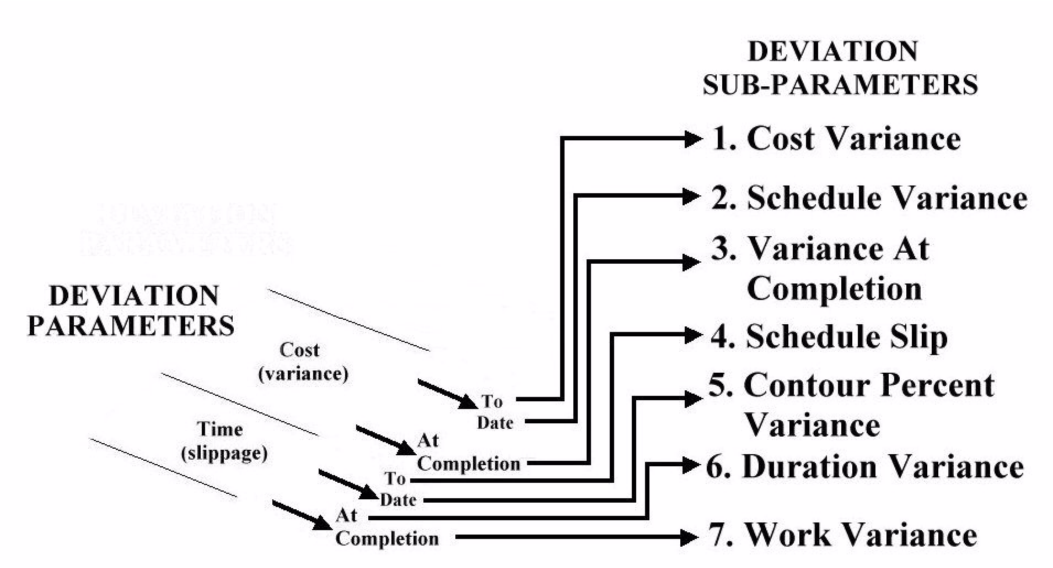

Figure 2. *A taxonomy of project planning data parameters*, source: author.

There are actually three types of planning values: baseline (predictive and pre-project), estimated (revisions to baseline values made during a project) and actual. Before a project starts, all of its values are of the type 'baseline'. After commencement, uncertainty is slowly replaced with certainty. Values before any given project time 'T' are gradually transformed into the type 'actual'. Values after project time 'T' move towards 'estimated', as the baseline is revised. It is almost necessary to suggest that all baseline values become estimated values, at project commencement. Eventually, all values become actual values. Project progress reports are usually based on either actual *and* estimated data or just actual data. Reports using actual and estimated data may be termed 'at completion' (see Fig. 2). They predict the outcome at completion of the project, based on current status. Reports using only actual data may be called 'to date' (see Fig. 2), as they only consider progress up to project time 'T'. Project planning is essentially concerned with project data concerning 'time' and 'cost' (see Fig. 2). Reports generated for either of these parameters may be of the type 'at completion' or 'to date'. Time and cost may be categorised as 'deviation parameters'. That is to say, they can be used to measure deviations from the project baseline. Further to this, there are a variety of measurements that can be made for each of the deviation parameters. The most frequently used and relevant of these 'deviation sub-parameters' are-

Cost deviation parameter/reporting to date:

- COST VARIANCE (No. 1, Fig. 2), units £s. At this point in the project, is completed work on this task over budget?
- SCHEDULE VARIANCE (No. 2, Fig. 2), units £s. At this point in the project, how are we doing on this task compared with the estimated spend ?

Cost deviation parameter / reporting at completion:

- VARIANCE AT COMPLETION (No. 3, Fig. 2), units £s. At the end of the project, what is the difference predicted to be between the current estimate of the total cost for this task and the original estimate?

Time deviation parameter/ reporting to date:

- SCHEDULE SLIP (No. 4, Fig. 2), units days. At this point in the project, what is the difference between the elapsed time estimated and the actual elapsed time.
- CONTOUR PERCENT VARIANCE (No. 5, Fig. 2), units percent. At this point in the project, have the expected percentage of the allocated person hours been used up (given that the task may have a non-flat resource contour and therefore not be directly comparable with the percentage of duration completed)?

Time deviation parameter/ reporting at completion:

- DURATION VARIANCE (No. 6, Fig. 2), units days. In Earned Value Management terminology, this is sometimes called Projected Program Delay. At the end of the project, what is the difference predicted to be between the current estimate of the total time to complete this task and the original estimate?
- WORK VARIANCE (No. 7, Fig. 2), units hours. At the end of the project, what is the difference predicted to be between the current estimate of total number of person hours to complete this task and the original estimate?

Table 1 illustrates an example of project planning data generated from the project management software package, Microsoft Project. In a later section of this paper, tasks from the same example project will be shown transformed into tabled data. It should be noted that a third deviation parameter might be described as 'conformance' or 'quality'. Objective measurement of this parameter is not a simple matter. As yet, conformance has not been implemented in the Procession software tool. Whilst recognising its importance to construction projects, it has temporary been omitted from further discussion.

Table 1. *Example of acquired raw project planning data*, source: author.

Dates			
Start:	Thu 30-12-99	Finish:	Thu 06-01-00
Baseline Start:	Wed 29-12-99	Baseline Finish:	Tue 04-01-00
Actual Start	Thu 30-12-99	Actual Finish:	NA
Start Variance:	1 day	Finish Variance:	2 days

Duration			
Scheduled:	6 days	Remaining:	3.18 days
Baseline:	5 days	Actual:	2.82 days
Variance:	1 day	Percent Complete:	47%

Work			
Scheduled:	80 hrs	Remaining:	42.4 hrs
Baseline:	64 hrs	Actual:	37.6 hrs
Variance:	16 hrs	Percent Complete:	47%

Costs			
Scheduled:	£3,040.00	Remaining:	£1,640.00
Baseline:	£2,440.00	Actual:	£1,400.00
Variance:	£600.00		

Task Status		Resource Status	
Tasks not yet started:	0	Resources:	2
Tasks in progress:	2	Overallocated Resources:	0
Tasks completed:	0		
Total Tasks:	2	Total Resources:	2

3. A 3D FRAMEWORK FOR CONSTRUCTION PLANNING

The field of computer systems engineering has a long tradition of employing three dimensional frameworks to analyse its constituent processes. Underlying this is the deconstruction of morphological form to reveal inherent properties. This approach has much in common with the cognitive amplification methods used in information visualisation. An early systems engineer, Hall describes morphological analysis as decomposing "a general problem or system into its basic variables, each variable becoming a dimension on a morphological box."[2] Generally, construction industry process modelling seems not to have adopted a similar approach. However, recent commentators on project management (for example, Forsberg et al.)[3] have described a project in terms of three 'aspects'. The unique intention in this research is to move from the more general case of 'projects', to the emergent properties of 'specific projects'.

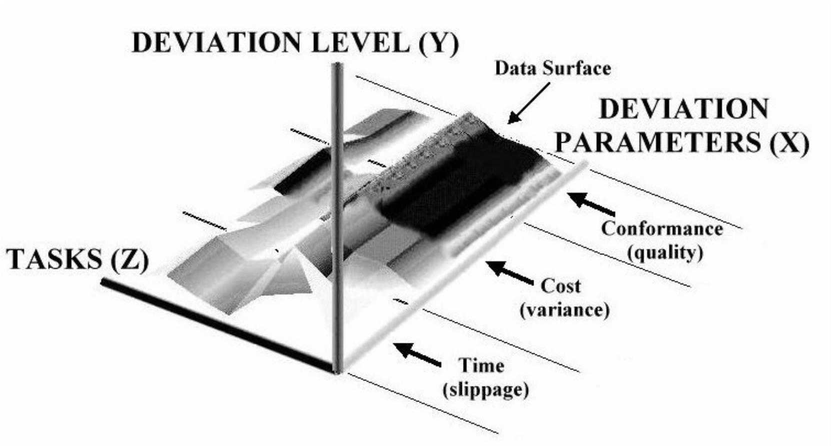

Figure 3. *A 3d framework for construction planning* source: author.

The use of 3D graphics, only seems justifiable if it adds to the intelligibility of a data set. An approach for construction process data will now be proposed. It is suggested that the concepts used for Hall's three dimensional systems engineering framework may prove readily applicable to the interpretation of construction processes. This is suggested not only in the conceptual sense (as with systems engineering) but also for the more literal representation of processes through information visualisation . Figure 3 shows the conceptual framework, with 'deviation parameters', 'deviation level' and 'tasks' as its three dimensions. Deviation level represents units of time or money, which deviate from the flat terrain of the project baseline. Figure 4 presents the 3d framework with the addition of the deviation sub-parameters, previously introduced in Fig. 2.

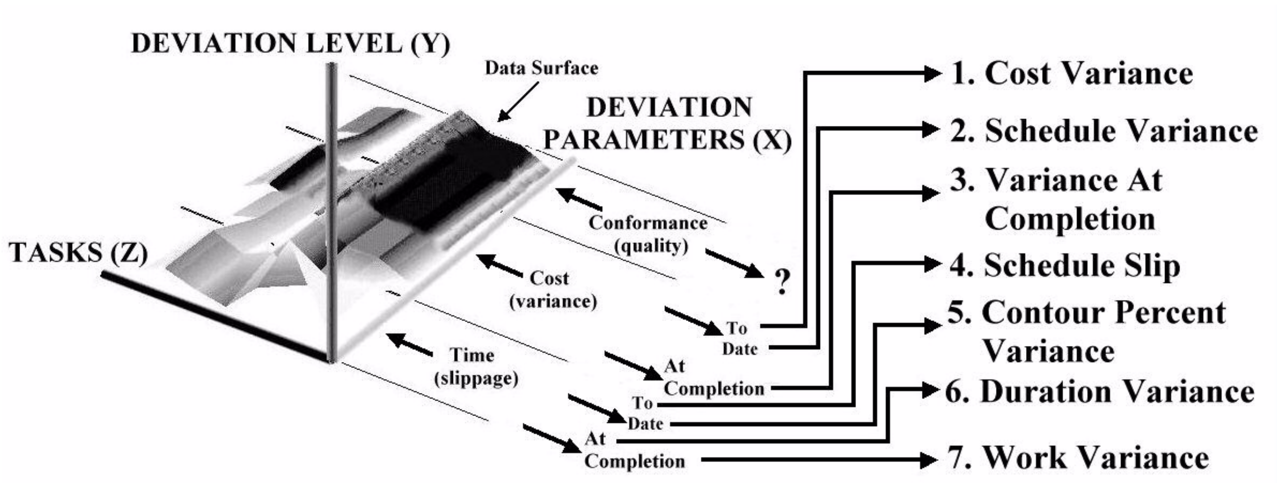

Figure 4. *A 3d framework for construction planning (including deviation sub-parameters)* source: author.

4. TRANSFORMING PLANNING DATA INTO 3D VISUAL STRUCTURES

Table 2. *Example of project planning data transformed into a table*, source: author.

TASKS	ELECTRICAL	PLUMBING
COST VARIANCE	£0.00	£0.00
SCHEDULE VARIANCE	-£320.00	£0.00
VARIANCE AT COMPLETION	£320.00	£280.00
SCHEDULE SLIP	0 days	0 days
CONTOUR PERCENT VARIANCE	0%	0%
DURATION VARIANCE	1 day	1 day
WORK VARIANCE	8 hours	8 hours

Shroeder et al. state that: "a major challenge facing information visualization researchers is to develop coordinate systems, transformation methods, or structures that meaningfully organize and represent data."[4] A common theme across recent publications on information visualisation, [5 and 6] is its distinction from other three dimensional computer graphical models. Whereas, systems that might be described as desk top virtual reality are defined purely by their graphics, information visualisation technologies have a pre-requisite dependence on *transforming* their target data. Table 2, shows the same data set previously shown in Table 1. This has now been exported from the project management software. It can now be seen that this very simplified project contains two tasks, 'electrical' and 'plumbing'. The tasks are showing values for all of the deviation sub-parameters. This tabled data can next be visualised, by applying the 3d framework described in section 3. The three framework dimensions map to Procession's data surface, as follows:

- The X axis maps to the deviation parameters dimension
- The Y (height) axis maps to the deviation level dimension
- The Z axis maps to the tasks dimension.

The values for X and Z define a 2d plane, with Y providing the height scalar values. Therefore, a project with no deviations from the project baseline will produce a flat data surface.

5. INTELLIGENT FILTERING AND SIGNIFICANCE RECOGNITION

Procession's data surface has a fourth non-spatial dimension, its colour. This scalar value represents the significance of each deviation, to this specific client. It is intended that Procession will use artificial intelligence techniques to 'learn' from project to project. By analysing the contribution of each deviation to project outcome, Procession will develop a set of heuristics concerning each task's contribution to overall project deviation. By maintaining a 'legacy archive' between projects, Procession uses colour to warn about a deviation (however small) that has had severe outcome implications for previous projects. It should also be able to make decisions about the relevance of data and which tasks to filter out, in order to provide only a summary. Work will focus on developing a significance of deviance algorithm, which would seem to need to answer the following question:

- How significant is *this* task to the current total value for *this* deviation parameter in *this* project?

6. TECHNICAL PROFILE

Procession is a stand-alone application developed for the Microsoft Windows 95/98/NT platform. It is capable of opening data files both from a local computer and from an Internet web server. Procession is an MDI (Multiple Document Interface) application, which is to say that it can have several visualisation windows open simultaneously. Procession was developed in the C++ language, utilising the MFC (Microsoft Foundation Class) library version 4.21. The principal reason for selecting an MFC application framework over the more traditional Win32 API, was MFC's provision of straightforward HTTP client coding through its WinInet Classes.

Procession's 3d graphics functionality is provided by VTK (the Visualization ToolKit), an 'open source' system providing a C++ class library, and a choice of Tcl/Tk, Java, and Python as interpreted languages. VTK runs on both the Unix and Windows platforms and its design and has been driven by the principles of OO (Object-Orientation). VTK's graphics model allows abstract modification of properties at a much higher level than alternatives such as OpenGL. In addition to its graphical functionality, VTK also provides a useful library of manipulative algorithms including scalar, vector, tensor, texture, and volumetric methods. VTK features advanced modelling techniques such as implicit modelling, polygon reduction, mesh smoothing, cutting, contouring, and Delaunay triangulation.

To date, work on Procession has shown that it is relatively easy to derive new C++ classes from VTK. In terms of negative observations, VTK trades off achieving the highest graphical speeds in return for its platform independence. The outcome of this is that it requires a reasonably fast computer to make best use of its full graphics capability. Procession's data surface is actually a 'carpet plot', generated by a scalar algorithm. The three dimensions are achieved from a two dimensional set of points which are warped by scalar values, in the direction of the surface normal. The amount of warping is controlled by the scalar value. The point set is determined by the 3d framework's 'tasks' and 'deviation parameters' dimensions.

The scalar (or height values) are provided by the framework's 'deviation level' dimension (see Fig. 4). A fourth and non-spatial dimension is provided by colour mapping the data surface. This equates to the significance of the deviation level, as calculated by intelligent filtering and significance recognition (see section 5). It is envisaged that Procession will be used on an 'entry level' office PC. As such, it is seen as important that the client should be able to multi-task (word processor, web browser etc.) whilst running Procession in the background.

7. EVALUATION METHODOLOGY

It is intended that the next phase of the research will focus on an evaluation of Procession. The main aim of this is to determine whether clients *perceive* Procession's progress reporting information to be more useful than currently utilised approaches. As a secondary aim, it is hoped that the evaluation will prove informative concerning the suitability of the conceptual 3d framework. In order to evaluate Procession, comparative research will be conducted, making use of interview protocols and rapid prototyping. This evaluation is intended to determine a selected construction client's level of satisfaction with the quality and format of the project progress information provided. In order that Procession's informational provision improves on the current model, a requirements capture stage will be undertaken.

A planning data set will be obtained from a 'live' construction project. It is desirable that this data comes from a construction client, or professional practice, not involved in the prototype evaluation. Ideally, this data will take the form of a Microsoft Project file. The researcher will then use the skeleton of this live project to create simulated projects, with different sequences and outcomes. The purpose of this is to provide a testing ground for Procession, which must be unfamiliar to the construction client (there would be no motivation for information requests). A precedent can be found for this approach in Hackos and Redish's description of similar simulations as 'Prototyping Scenarios'[7]. Each of the simulated projects will have weekly 'snapshot' files produced, to represent the chronological sequence through the project. These files will be stored on the researcher's laptop computer, in the CSV (Comma Separated Value) format. The prototypes will be evaluated by several different construction client volunteers. The interview questions will consider the quality of information provided by the construction clients' current methods of progress reporting, allowing for later comparison with the prototypes. Construction clients will also be asked about their general familiarity with computers.

After working with each prototype, construction clients will describe their perception of information quality. One protocol section will relate to functional aspects of the software prototype. Its purpose is to assess not the quality of the information that Procession presents, but the usability of the software. As such, reference will be made to standard guidelines for user-interface design. In order to verify construction client's *actual* level of informational understanding, the data for each of the simulated projects will include one or more 'problematic issues' (i.e. an apparently trivial deviation factor that might result in catastrophic project failure). These issues will be specifically fictionalised to be more obviously detectable in Procession, than with traditional reporting methods. The protocol will contain questions relating to the construction clients' awareness of these hidden issues. The use of observers to record and analyse how users perform tasks is an accepted methodology within (amongst others) the field of Requirements Engineering. It has been argued that, where an observer is physically present, notes taken should be of not only the user's exact behaviour but also of the observer's inferences concerning this behaviour.[8] Inferences may provide vital insight and so provision will be made within the interview format for these to be recorded.

The 'snapshot' weekly files will be used to compress a project of several weeks into as many minutes. For this research, it has been decided that 'real time' simulation of a project is not practical. For example, a construction client's need for information concerning the progress of 'on-site' projects is likely to make up a vital, but proportionally small part of their workload. As the requirement for this information may happen at unpredictable times, it does not seem a sensible use of resources to attempt direct observations of the construction client's behaviour on a 'live' project. Separate verification of three further Procession aspects will be conducted by independent and suitably qualified individuals.

These aspects are:
- the software installation process
- Procession's ability to access ISO (International Standards Organisation) standard 10303: STEP (Standard for The Exchange of Product model data). This covers the exchange of data between software applications in the manufacturing and construction industries. An example of this is the University of Salford's WISPER database.[9]
- Procession's ability to 'learn' from project to project, using a significance algorithm to provide both a colour scale for the data surface and a rational for the filtering of tasks.

8. CONCLUSIONS

This paper has proposed a conceptual 3d framework for construction planning and its implementation as a project progress reporting tool. Procession is now able to generate a data surface from a project planning data set (see Fig. 5). The next phase of the research will focus on implementing the software evaluation methodology. It is hoped that mean scores for the satisfaction of clients' information requirements, will be seen to increase while moving from their current reporting methods and through the Procession prototypes. In addition, it would be very positive to report types of informational deductions made possible by Procession, that were not present with clients' traditional reporting strategies.

Further work on Procession is also expected to develop an 'intelligent' algorithm for calculating the significance of data surface deviance levels. As the 'learning' element is not the primary research focus, it is anticipated that future work may be required to develop the ideas initialised in this area. Also beyond the scope and focus of immediate research goals is the integration of the un-addressed deviation parameter, 'conformance' (quality). Given the great significance currently placed on 'quality assurance', it seems likely that developing Procession's third deviation parameter may provide an interesting area for further work.

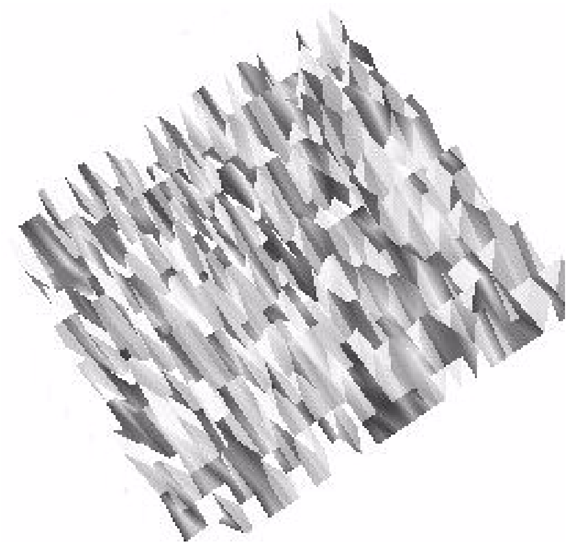

Figure 5. *Example of prototype 3d data surface*, source: author.

9. ACKNOWLEDGEMENTS

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