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Collaborative architectural design of sustainable buildings - The COLAB case

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This article first gives an example of sustainable architectural design and shows that collaborative methods are needed. A new research lab called Protospace was developed for that, but if team members can not be present they should be able to participate over the Internet. There are no good examples of truly collaborative architectural design. Therefore the author developed a multi-player Virtools prototype for the collaborative design of a 3D conceptual building layout on the Internet where sustainability is assured by the use of a criteria overlay matrix. That is the COLAB project. A team consisting of an architect, a structural advisor, an installation advisor and a cost advisor tested the method and prototype. The conclusion is that the participants need training before collaborative architectural design with this method and prototype can be efficient. The author passed his doctorate exam in February 2008 on this subject.

Keywords: sustainability, collaborative design, virtual reality, parametric design, design evaluation

1 Introduction

The built environment is our habitat. This word is used in Ecology to address the circumstances that make species flourish or not. Our habitat should be built with all stakeholders in mind. Municipalities could play an active role in this. They should not only approve or ask for changes in the plans, but actively interfere from the start with the design of the habitat of its citizens. Municipalities could demand for design teams with delegates representing all stake holders (including the building professionals). Such multi disciplinary design teams can develop designs that fulfil the needs and demands of all concerned.
Figure 1 shows a design that did that. It dates from 1984 and it was called ‘The Egg’. The feasibility study for this innovative office for the multidisciplinary centres of Delft University of Technology took two years. The design comprised a floating foundation (we already thought about the raising sea level at that time!), a roof made of round wood, collection and treatment of rainwater, heat storage in salt, fish culture and vegetable garden. After two years it turned out that there was a negative return of investment, mostly caused by the expensive foundation. In order to speed up and to improve the design of this kind of innovative buildings, multidisciplinary ICT projects were initiated. The conclusion at that time was that a sustainable building is a building that is optimized with all criteria of all stake holders. This asks for collaboration of many disciplines. ICT was supposed to make that possible.
Twenty five years ago only a few architect offices worked with computer systems. The Union of Computer using Architects in The Netherlands (VCA) was founded in that period with 200 of the bigger architect offices and the author

was the director during its last six years until 1995. Foreign CAD-systems had to be adapted to the Dutch situation and big flexible floppy disks, where no more than 1 Mb could be stored, were the only way to exchange data. And the data were not exchangeable between different systems. In 2001 data are exchanged in 33% of the projects of bigger building companies.[1] But mainly in the later phases of the building preparation; design is still badly supported by CAD-systems.

1 **Dolmans, G.** & **Lourens, E.** (2001). ICT in de Bouw, Economisch Instituut voor de Bouwnijverheid, Amsterdam, The Netherlands

During that period buildings got more and more complex, because of more attention for the (inside) environment, the emerging of high rise buildings, underground buildings, difficult locations, desired flexibility, new materials etc. This complexity is also a reason for the emergence of design teams; it just gets too complex for one person.

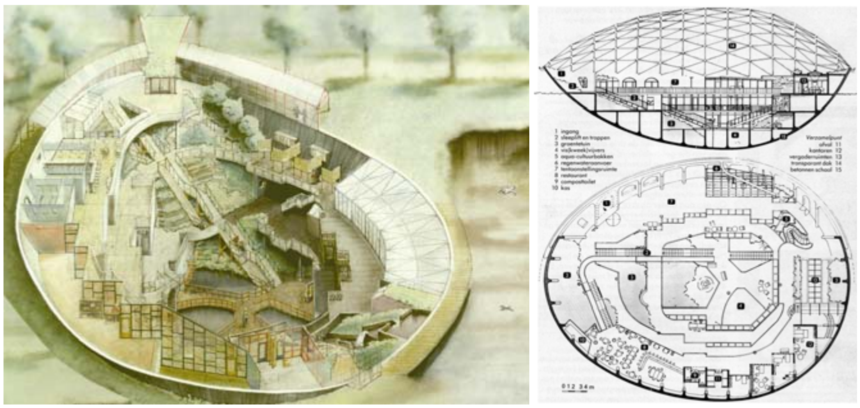

Figure 1 Ecological office building 'Het Ei'

Recent development of non-standard and interactive architecture with sensors, actuators and kinetic structures ask for even more knowledge (Figure 2).

Figure 2 Hessing Cockpit Utrecht, ONL. An example of Non-Standard Architecture

The term non-standard architecture refers to computer generated complex geometry which can be observed in many contemporary designs. With new parametric design software these complex designs can be adapted until the last moment and files can be sent to factories where the components of the building can be produced by Computer Numerical Controlled processes that keep these complex buildings affordable. The term interactive architecture refers to a new paradigm developed by Kas Oosterhuis. This paradigm consists of the theory, methods and techniques that make the concept possible of architecture displaying a real-time behaviour. This behaviour is sometimes triggered by users, but can also be pro-active and gives more identity to the buildings.

One of the reasons for this research was the reuse of the pavilion that Oosterhuis designed for the temporary agriculture exhibition Floriade 2000 - reuse is of course a proof of sustainability of this kind of architecture. It became the iWEB, with the collaborative design space Protospace. So iWEB is the name of the building and Protospace of the design system inside (Figure 3).

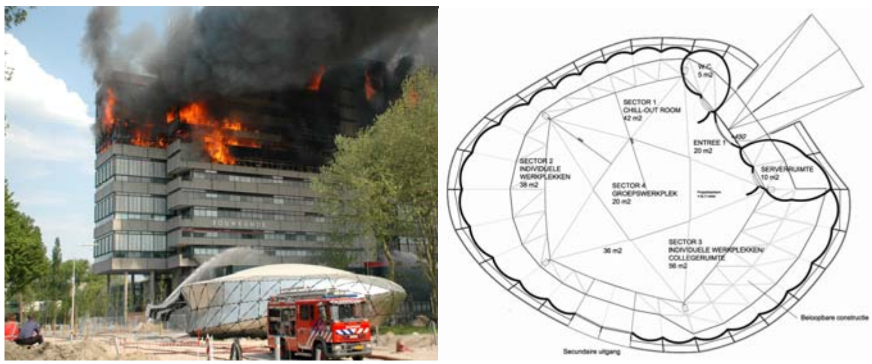

Figure 3 iWEB and Protospace. © Photo Rob Jastrzebski

Unfortunately on May 13 2008 the faculty got fire and is now completely demolished. Not an example of sustainability! But iWEB survived the disaster. In Protospace we develop methods of collaborative design with a team walking around between 5 screens. New interfaces are being developed as alternatives for keyboard and mouse.[2] Protospace is about local synchronic collaborative design. But what if team members can't be present and/or can't participate at the same moment. That is what COLAB studied: inter-local synchronic and a-synchronic collaborative design.

The COLAB project was initiated by the author in October 2005. This project developed a method and a prototype for the collaboration over the Internet of an architect, a structural advisor, an installation advisor and a cost advisor.

Collaborative design also emerges from the insight that the quality of buildings rises by good teamwork and the cost decreases.[3] It is a well known fact that most influence on the cost/¬quality ratio of a building lies in the very first conceptual design phase. It seems therefore a good idea to develop a method that permits all (or at least the most important) stake holders to design the concept together from the start. They can bring their specialised knowledge to the project and so prevent that the design starts on the wrong foot.

So the motivation of this research is manifold:

- at the start of a project there is the biggest influence on the cost quality ratio
- in order to design an optimal habitat we need the knowledge of all stakeholders
- we need to collaborate because buildings become more and more complex
- contractors want to be involved in the design because clients demand

2 Bongers, B. (2006). Interactivation, PhD dissertation, Vrije Universiteit Amsterdam, The Netherlands

3 Habets, J. (2001). Integraal ontwerpen als panacee voor alle bouwkwalen?. In: BladNA, 2001, 11, pp. 10-11 guaranties and high claims for failures

- there is a waste of time and money in design process if every team member has to regenerate data

2 State-of-the-art

Extensive search on the Internet and in literature gave no examples in practice for COLAB. In further research we found some vague mentions of collaboration during the design of buildings like Centre Pompidou in Paris, ING headquarters (remarks of colleagues) and some others, but it always turned out that some partial cooperation had taken place, but certainly not collaborative architectural design in the early conceptual stages of innovative projects.[4] Van Loon and van Gunsteren report some examples, but more on the preparation of the design than the design itself.[5,6]

The EC funded project ARTHUR described by Fatah and Penn comes closest to what we want.[7,8] The ARTHUR project is an augmented reality application through Head Mounted Displays with simulation of pedestrians influencing the collaborative design (Figure 4).

The software is VRML based and integrated with Microstation. The project was executed by the Bartlett Graduate School, University College London, Fraunhofer FIT, Aalborg University, SaabAvionics, Linie4Architekten, Foster and Partners. ARTHUR was used in three simple design assignments with students and visitors of a computer fair. Some observations have been made, like the change in design method with or without the system. But the assignment was too simple for the conclusions to be valid.

For examples of collaborative design we have to look at other fields of technology. E.g. in the space craft, aeroplane and car design collaborative design is very common. An example is the ICAD system; in the way it is used by the SIA group at the Faculty of Aerospace of Delft University of Technology in The Netherlands.[9] But during our introduction lessons in ICAD we came to the conclusion that it has a negative influence on creativity in architectural design. For the redesign of an airplane wing it is very suitable. Software products are commercially available that support collaborative design in these sectors. However the collaboration appears to be not without problems.[10] Next types are distinguished:

5 Loon, P.P. van (1998). Interorganisational design, Delft University of Technology, The Netherlands

6 Gunsteren, L.A. van and **van Loon, P.P.** (1975). Open Design & Construct Management, Delft University of Technology, The Netherlands

7 Fatah, A. et al (2004). Interactive Space Generation through Play. In: Architecture in the Network Society, Rüdiger, B., Tournay, B. and Ørbaek, H. eds, eCAADe, Denmark.

8 Penn, A. et al (2004). Augmented reality meeting table: a novel multiuser interface for architecttural design. In: 7th International Conference on Design & Decision Support Systems in Architecture and Urban Planning. Leeuwen, J.P. van and Timmermans, H.J. eds, Kluwer Academic, The Netherlands, pp. 213-220

9 La Rocca, G. et al (2002). Development of an ICAD Generative Model for Blended Wing Body Aircraft Design [www.lr.tudelft.nl]

10 Kleinsmann, M. S. (2006). Understanding collaborative design, PhD dissertation, Delft University of Technology, The Netherlands

Figure 4 The ARTHUR project [Fatah 2004]

On the actor level:
- The ability of actors to make a transformation of knowledge
- The equality of the language used between the actors

On the project level:
- The efficiency of information processing
- The quality of project documentation

On the company level:
- The organization of resources
- The allocation of tasks and responsibilities

3 Parametric design and evaluation

Since there are no good examples of collaborative architectural design a method had to be developed based on research of the design process and own experience. Different sources support the idea that the two main processes in design are creation and evaluation.[11 to 15] Creation is supported by parametrical design software. The process of evaluation consists of giving values to criteria. An extensive literature study showed that for the long-term knowledge based multi agent systems can be of great support to complex designs especially in the preliminary and later phases.[16] For the short-term a simple criteria overlay matrix can support the design team in finding the relevant issues to discuss. The discussion should take place in a chat box that is at least stored on the database for future retrieval. Better would be if a discussion forum could be used (Figure 5).

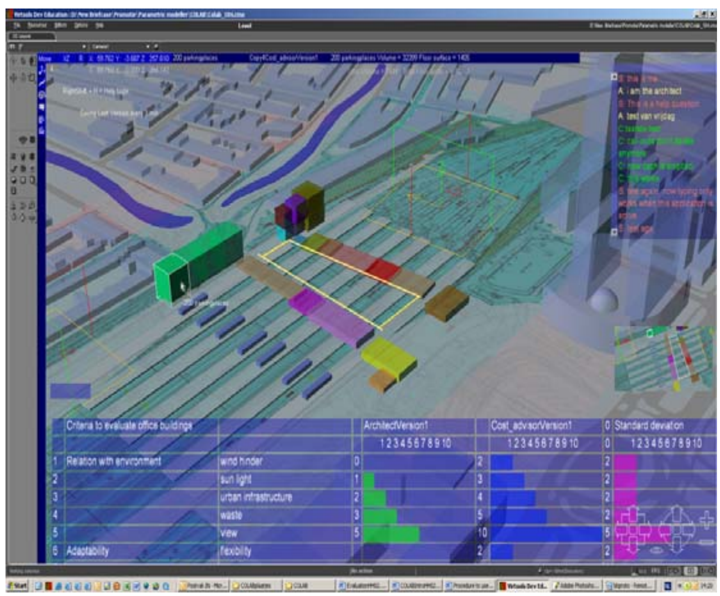

Figure 5 Criteria overlay matrix in COLAB

The use of explicit criteria in the design process is very important:
- It provides a possibility to participate in the evaluation of alternatives anywhere and anytime.
- By displaying the biggest difference in appreciation (standard deviation) in a bar chart, the most important subjects for discussion are rapidly discerned.

11 Foqué, R. (1975). Ontwerpsystemen, Het Spectrum, The Netherlands
12 Akin, O. (1986). Psychology of Architectural Design, Pion Limited, London
13 Hubers, J.C. (1986). Eindelijk een gebouw dat met alles rekening houdt: 'Het Ei'. In: Bouw, februari'86, pp. 10-14
14 Hamel, R. (1990). Over het denken van de architect, AHA Books, Amsterdam
15 Moughtin, C,R. et al (2003). Urban Design Method and Techniques second edition. Oxford: Architectural Press
16 Hubers, J.C. (2005). Design environment Protospace 1.1. In: AEC-2005 proceedings,. Tuncer, B. and Sariyildiz, S. eds., Millpress Science Publishers, The Netherlands

17 For an extensive -but Dutch- list of criteria categorized into relations with the environment (cosmos, atmosphere, hydrosphere, lithosphere and biosphere) consult Hubers.[18]

18 Hubers, J.C. (1986). ibid

- It can limit the influence of dominant stake holders.
- It prevents bad unconsidered choices for the environment.
- It forces to think at least of all listed criteria.[17]

It is impossible to design a building that scores 10 out of 10 on all criteria. Developing some alternatives gives a better chance to approach the optimum and a possibility for the stakeholders to discuss important issues. Of course building regulations and the program of demands give also input for the criteria list, because a demand or a regulation is nothing but a maximum or minimum value of a criterion. The discussion should list advantages and disadvantages of versions of the design. In a next version the first should be integrated and the last eliminated.

Figure 6 Swiss Re building designed by Foster and Partners (amateur photo)

Design is an iterative process. Many changes in the design occur during this process. The far from perfect communication about these changes to all concerned is a cause of errors and building failures. If we could succeed in developing software that automatically updates every bodies files, we could solve this. Parametric design software is promising in this respect. It is 3D modeling software where the parts of the design are not based on fixed dimensions but generated by the software based on parameters. A parameter is a variable that can take on different values. The variables are used in formulas that generate the parts. So e.g. the diameter of a tower is not set to 30 m but to X with an initial value of 30 m. Then the middle of the tower can be set to 1,2*X and the top 0,1*X. If later the client changes his demands, then with optimization algorithms the diameter X can be calculated so that the floor area is exactly what is needed. Already this simple example shows that it is very difficult to make a model where everything is related in a correct way, because certain functions on certain levels need maybe a different amount of space than the formula permits. Parametric design is also studied extensively and led to the choice of the variational approach, where relations between the parameters and the objects are both ways.[19] An example of parametric design software is Generative Components (GC). GC is based on Microstation of Bentley Systems. It is now commercially released, but the Beta version was already used by important institutes like Foster and Partners (for instance the Swiss Re building, Figure 6), Gehry Partners, Morphosis, KPF, Arup, Grimshaw, GLform, AA, MIT and ONL, the office of Oosterhuis, who invited mister Aish to give some workshops with Hyperbody. Essentially, parametric design, as implemented with Generative Components, opens new possibilities to explore alternative building forms and fabrication technologies, while at the same time addressing key issues in the efficient management of conventional design and documentation processes.[20]

19 Hubers, J.C. (2005). Parametric Design in Protospace 1.1. In: CAAD Futures 2005 - Special Publication, Mertens, B. and Brown, A. eds, ÖKK-Publishers, Austria

20 Aish, R. (2005). Introduction to GenerativeComponents, a parametric and associative design system for architecture, building engineering and digital fabrication, white paper [www .bentley.com]

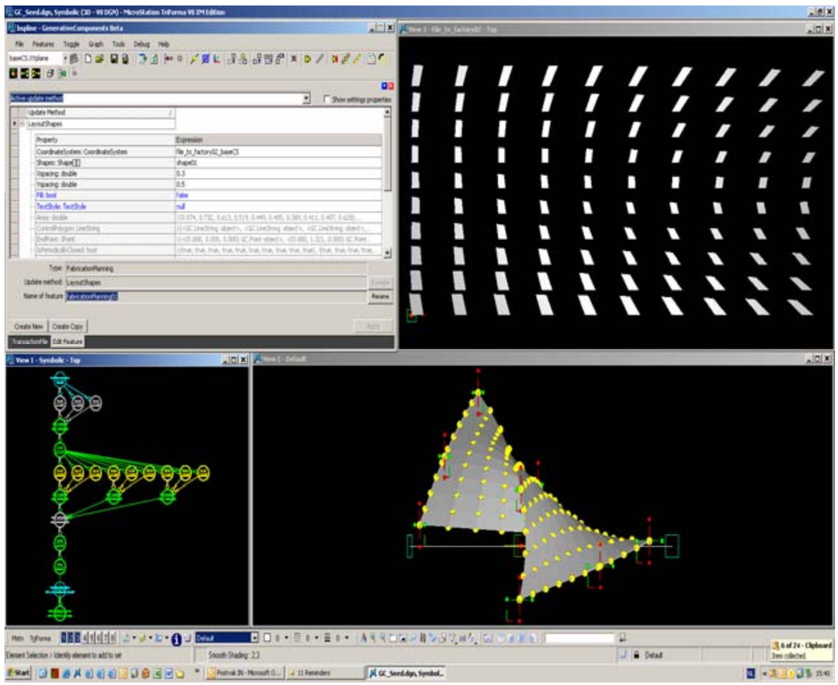

Figure 7 File-to-factory, dependency graph and double curved nurbs surface in GC

In shipbuilding parametric design was already common before computers were used. Complex curvatures are common in this field and components had to fit in different places in different directions and were therefore defined as parametrical objects. In GC components can be anything, a single numeric parameter, a line or a complex array of double curved surfaces. It is in the relation of these components that GC has his strength. By changing one or more of the components the design is regenerated without the need of redrawing manually.

Though very inspiring, GC is it not suitable for quickly developing a layout of a building. It is better used in the phase after that. The same goes for Digital Project of Gehry Technology, which we started using recently too. Also because COLAB needs multiplayer internet functionality we had to develop our own prototype software application. We use the multiplayer game development software Virtools for that (Figure 7).

4 COLAB Method and Prototype

The method consists of importing the Program Of Demands (POD) with its m^2 and m^3, functions and constraints in a 3D model of the environment. The Virtools prototype converts this information into half transparent coloured volumes with function names above them. Different local tools support the division and distribution of these Functional Volumes over the site. They can be visualised as blocks or as spheres (Figure 8). This work is done by every team member separately resulting in versions of the lay-out in a central database.

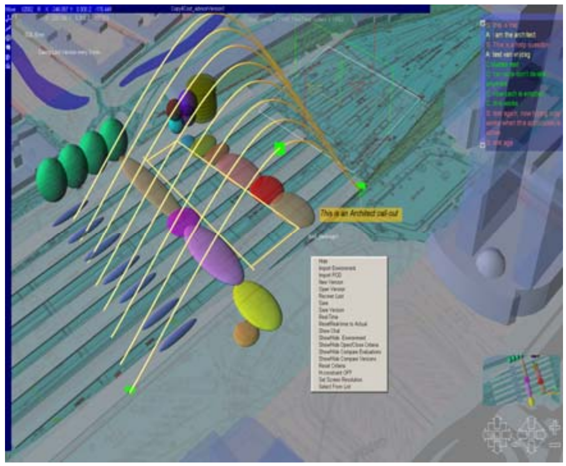

Figure 8 The COLAB prototype

This work can not be executed simultaneously in multi-player mode, because if one team member is trying to make a tower out of the volumes, while another is making a square, they will never get to a result. Messages show when team members save their work, so the others can cycle through the versions and give their comments or continue working on a particular version.
When there are enough versions, the team members discuss them through textual chat and a criteria overlay-matrix, which they complete with relevant criteria (Figure 5). Both are stored in the database. They summarize this in advantages and disadvantages of every version of the concept. Then a next round follows, where they try to integrate the advantages and eliminate the disadvantages. Finely the team members choose one version. This volumetric model can be used as a reference layer for the next phase: the actual design (Figure 9).

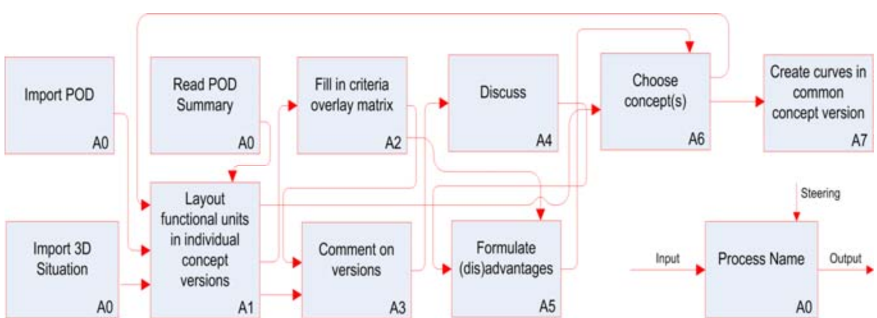

Figure 9 COLAB IDEF-0 Process diagram

Now every team member shows which building elements are needed and what they look like. They do this from the point of view of their own discipline, so this can be simultaneous. The tool the author developed for this is a multi-player Virtools application that supports multicoloured 3D curves. The structural advisor uses red lines for the supporting structures, the installation advisor blue lines for the conducts and other installation elements, the architect makes yellow lines showing his design intentions (Figure 8). They put arrows with comment (call-outs), while chatting and using the criteria-overlay matrix. The cost expert, who doesn't draw lines, interacts through comments. The same method with versions will lead to the final concept.

Finally the result will be exported to the various software applications of the team members for further calculations and modelling.

The prototype that supports this method has been developed by the author in 837 hours. The motor of the application is the continuous looping of Upload and Download scripts that take care of the exchange of data with the database over the Internet and the New Data Script that waits for the message that the data can be processed (Figure 10 and Figure 11). The data are always exchanged as whole tables and after a first start only new rows of the table are processed. This turned out to be the best and fastest way. Processing the data comprises for example the distinction between creating, deleting or editing objects according to the column of the database that shows which action has to be taken.

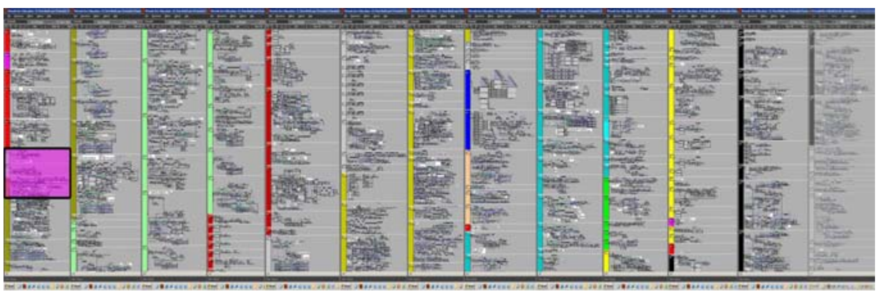

Figure 10 Zoom out on Figure 11

5 Discussion

The method and the prototype are tested twice by a team consisting of an architect, a structural advisor, an installation advisor and a cost advisor, all with ample experience in practice. As a case study the team was asked to develop a design for the new Rotterdam Central Station. One week before they got the program of demands and the same additional information as the real participants of the design contest. The first test showed that only the architect was capable of creating a concept, the others had too much trouble with the 3D software and were also not capable of suggesting a concept. The criteria matrix was hardly used. The second test was about the real-time collaborative design on the concept of the architect. But instead of drawing lines they preferred to manipulate the Functional Volumes and had much trouble with that in the prototype. The discussion in the chat box was rather poor and mainly focused on the idea of the architect to put the parking in the middle of the plot. Every team member wrote a chapter in an internal report regarding the input-processing-output of data for his field. They also evaluated the tests.

21 Hubers, J.C. (2008). Collaborative Architectural Design. In: Virtual Reality, PhD dissertation. Delft University of Technology, The Netherlands

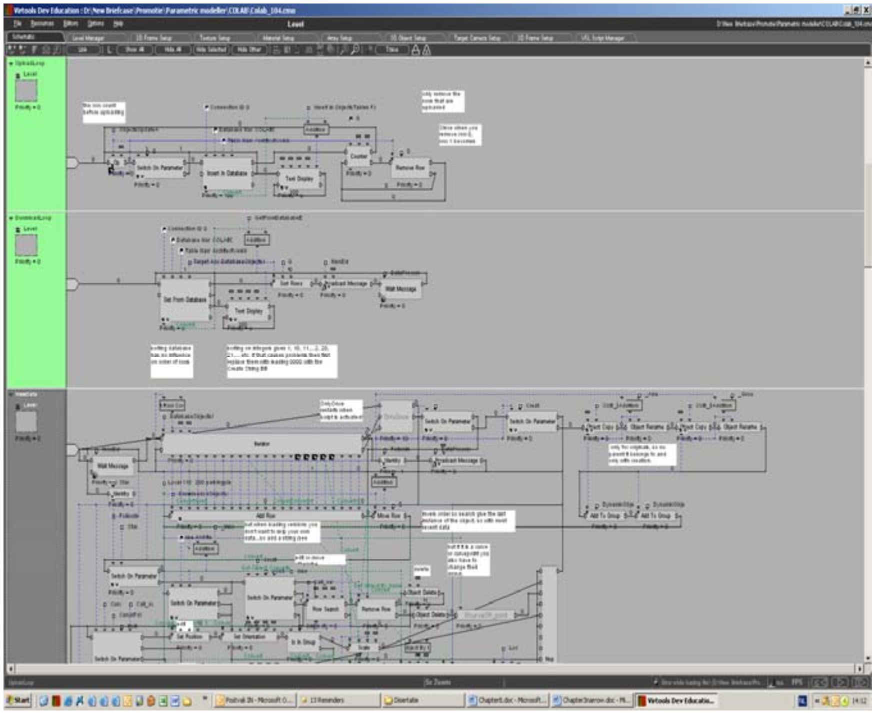

Figure 11 Upload, Download loop and New Data script (partly)

In the dissertation about this subject it comes down to the next advantages and shortcomings.[21] The architect finds that he should develop the form of the building in close relation to the client. Every stakeholder should have the authorisation to make their expert decisions in the design process. The form is his expertise and he doesn't support the idea of developing an overall concept of the layout of an architectural project together with advisors.
The structural advisor is much more positive about the collaboration in the test and puts forward the necessity of knowledge exchange. This is education and is better organized in schools than in practice.
The installation advisor complains most about not getting involved from the start of projects. Decisions that could avoid problems with wind hinder, overheating in summer, sound hinder, acoustics etc. should be taken in an early stage, otherwise only expensive solutions or no solutions at all can be found. He also indicates that intensive training is needed before his profession could contribute in the 3D design of the architect.
The cost advisor states that a design manager is needed to guide the collaboration. Like the other advisors he is not used to work with incomplete information and to develop with trial and error an overall concept for a building design.
Of course this single test doesn't give scientific proof about the validity of the method and prototype. But strong indications for further research are useful too. The test maybe indicates the reasons why truly collaborative architectural design - so multidisciplinary from the start- can not be found in practice.
There is a lack of knowledge about each others domains and a lack of time to

explain certain decisions, or the will to spend this time. But in a scientific environment these are speculations. The research permits only next conclusions.

6 Conclusions

The main conclusions of the research are:

1. It appeared to be possible to develop a working software application prototype in Virtools with which a multidisciplinary design team can cooperate in a virtual 3D environment in real-time on the Internet.
2. Only the architect in the test team appeared to be able to develop an integral concept with this prototype.
3. The advisors in the test team need training in developing and 3D modelling of conceptual building designs. Only after that they could be able to effectively participate in multidisciplinary architectural conceptual group design based on this method and prototype.

The last conclusion unfortunately brings the efficiency of collaborative design on a lower level because training takes time and money. Estimations of the participants in the test vary from 1 – 100 hours. In order to design buildings that fulfil better the criteria of all stakeholders, training in collaborative design is necessary in the education of the concerned disciplines. As long as this is not the case, it seems reasonable to have the architect make the conceptual building design, eventual with real-time comments of the advisors. Only after the concept is ready, real-time data exchange between the members of the design team is relevant.

The Hyperbody group started to investigate the possibilities of data exchange between the applications that the team members normally use. We also started research into morphogenomics, where with the use of e.g. genetic algorithms the conceptual work is done by the computer and advisors only need to evaluate if the survival of the fittest design is fit enough.[22] For the short term however we expect good results with ad hoc data exchange in Protospace, and are starting up real life show cases, where sustainability is assured by the use of criteria lists.

22 **Billoria, N** and **Hubers, J.C.** (2008). Morphogenomic archi-tectture. In: proceedings of the 5th International Conference on Innovation in Architecture, Engine-ering and Construction (AEC2008), Turkey

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Instructions for Authors

All papers are reviewed by at least two reviewers. All reviewed and accepted papers have to be resubmitted, implementing reviewers and editors comments or suggestions. Only accepted papers conforming to instructions will be considered for publication in the *International Journal of Design Sciences and Technology*.

The first page of the paper must contain the full title of the paper as well as the name, affiliation, address, telephone, fax and email of the main author and co-authors (if applicable). Also mention the name, postal address, telephone, fax and email of the author to whom all correspondence to be directed.

The second page should contain the full title of the paper, the sub-title (if any), an abstract of 100 to 150 words summarising the content of the paper and 3-5 keywords for the purpose of indexing (the use of references in the abstract is discouraged). Maximum length of a long paper is 7000 words (4000 words for short papers). Please note that the use of Footnotes and endnotes are discouraged. The layout of the journal allows the use of 'side notes' (see a sample issue of the journal). Where appropriate give information for the 'side notes' (maximum length 60 words) between double square brackets (such as full bibliographic reference, page numbers, remarks and notes). All side notes should be numbered consecutively. For instance: [[17 A 'side note' reflects additional information, a reference or the URL of a website]]

The paper will be written in (UK) English. It will be single-spaced with 30 mm margins on all sides (paper size A4). Use Times New Roman for the main body of text (size 10), figures (size 8) or tables (size 8). The use of **Bold**, *Italics*, ALL CAPS, SMALL CAPS, etc. is discouraged. All chapters should be numbered consecutively (more than one level sub-headings are discouraged). All Figures and Tables with their respective captions should be numbered consecutively. They should each, be placed on a separate page, at the end of the paper. All figures, tables and equations should be mentioned in the body of text. Give an approximate insertion point for figures and tables, between double square brackets. For instance: [[insert Figure 5]]. You will be asked to resubmit your drawings if necessary. **Do not layout your paper**. *Do not use any styles or any automatic layout system.* Please do not use 'Track Changes'.

All Tables should be referred to in the text as Table 1, Table 2, etc. All Figures should be referred to in the text as Figure 1, Figure 2, etc. Line drawings should be of good quality. Use light background if possible (white is preferred). Photographs and screen-shots should also be submitted separately as JPEG files (use high resolution for better results). Authors should prepare high quality figures and drawings. Avoid the use of colours in your illustrations, as the journal is not published in colour. Maximum width and height of a figure are respectively 115 (150 mm if absolutely necessary) mm and 190 mm. Maximum width and height of a table are respectively 115 mm (150 mm if absolutely necessary) and 170 mm. All Equations will be numbered consecutively and should be mentioned in the text.

Use 'Harvard System of Reference'. Bibliography (references) is collected at the end of the paper, arranged in alphabetical order by the first author's surname, followed by initials. All authors should be mentioned. Dates will appear between brackets after the authors' name(s). This is followed by the title of the book, name of the publisher, place of publication and page numbers (if applicable). To refer to a journal paper, add the full title of the journal followed by Volume:Issue Number and page(s). Examples of references to a book, a journal or a website are shown below:

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