MORPHOLOGICAL ANALYSIS OF A SUSTAINABLE SCHOOL DESIGN

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ABSTRACT
The built environment has to become more sustainable. Principals experiment with different ways to stimulate sustainable innovation. Instead of just asking an architect they now ask for Integral Design teams, in which designers from different disciplines start designing together almost from the same moment in the design process. The design competition session for the conceptual design of a sustainable school was put on video and analyzed by applying morphological analysis. This analysis is based on a functional transcript of the process and the transforming of that in to a morphological overview. This analysis is done in two ways: one focusing on the process interactions and one more focusing on the functional aspects of the design process. Some results of the analysis are presented especially focusing on the difference between architects and engineers in the design process.

Keywords: design competition, integral design, morphological analysis, functional transcript

1 INTRODUCTION
The design of buildings is complex especially in relation with providing comfort for the occupants during winter and summer. As a result the built environment uses 40% of all our energy for conditioning the buildings. Building designs need to provide solutions for increasingly complex programs of requirements, especially related to sustainability issues ranging from flexible use to energy saving measures while maintaining and even increasing comfort level of the users. Therefore building design involves many experts from different disciplines. As complexity and scale of design processes of buildings increase, traditional approaches may no longer suffice (van Aken 2005).
Principals experiment with new ways of tendering projects to stimulate change. The project which is described in this paper is about the design of a sustainable school. Actually two school organizations have merged and want one new school building in which both organizations still can have their own identity. More important they want to have a sustainable school as a good example of their responsibility to society. In other to stimulate sustainable innovation the principal asked for integral design teams to come forward with a conceptual design based on a fixed given budget. In this tender, architects, structural engineers, building services engineers and building physics engineers were only allowed to participate in only one of the tendering teams. As a result teams competed with each other on the basis of the quality of their vision and their conceptual design. This is not unusual anymore and this form of design competition is becoming a trend.
The design team came together a week before the presentation to discuss the design brief and to make together a conceptual design. The initiative for forming the design team came from the architect and was based on earlier experiences with the individual engineers. So all design team members knew each other all ready quite well. The architects prepared some documentation which was sent to the invited participating engineers. Also sent to the engineers was a conceptual solution for the school by the architects.
As such the design competition in which the design team was coincidentally involved seemed a good example as it was a real actual design process at hand. The design team allowed to video tape the whole design competition session, which is quite unique. The video was used to analyze the design session in which worked together two architects, a structural engineer, a building physics consultant and a building services consultant. The outcome of this session was translated into a functional transcript, which was used to create a morphological overview of the session. This enabled us to analyze specific the communication during the conceptual design process.

2 METHODOLOGY

In contrast to models which conceive designing as a strict goal-directed process, an interpretative approach is suggested: a kind of methodical reorientation exploring whether previously neglected design methods can be adopted for use as analytic tools for design meetings.

Even though design undoubtedly includes stretches of 'normal' ill-structured problem solving (Dorst and Rooyakkers 2006) any model or description method that tries to reduce design to ill-structured problem solving is bound to miss important aspects of the design activity (Hatchuel 2002). Still understanding the intricacies of the design process is essential in solving ever more complex problems (Lloyd et al. 2006). There are many ways and many different possible tools to analyze design meetings (Cross et al. 1996, Goldtschmidt and Porter 2004). Over the last 10 years several international research centers performed empirical studies of design, looking at design in so-called situated contexts (Lloyd et al. 2006):

- interaction analysis to look at collaborative design activity, Stanford University's Centre for Design Research (Tang 1990).
- modelling team-based design activity using methods developed in computational linguistics, the Key Centre for Design Computing at the University of Sydney (Dong 2005).
- viewpoint methodology, based on the work of Bucciarelli (1995),
- to study group design activity by INRIA, the French National Institute for Computer Science and Control (Detienne et al. 2005).
- semiotics in looking at architectural design, Medway and Clark (2002) and Luck (2003).
- functional linguistics to understand expertise in engineering design, McDonnell (1997)
- ethnomethodology to analyse mechanical design meetings, Hugill (2004).
- interaction process analysis in looking at the construction industry, Gorse and Emmitt (2003).
- adapted models of cognitive ethnography to study designers, Ball and Ormerod (2000)
- discourse analysis to study engineering design, Reid and Reed ((2005) and Lloyd (2002).

Different studies of designer teams formed the basis for the Design Thinking research Symposium 7 in 2007 to stimulate debate and dialogue on design research specific focused on the analysis of design participants (Lloyd 2006). However the challenge is still to find ways in which traditional modes of designing can complement, and be complemented by, new technologies (Lloyd 2006). As most of the present design analysis methods are very time consuming there is a need for faster methods to be able to analyze more design sessions.

2.1 Morphological analysis

Recognizing the fact that design is not merely a problem solving activity, maybe one of the existing prescriptive design methods could help to understand design by using them for research, rather than (as originally intended) for design activities. Especially the use of morphological charts for analyzing design activities in the conceptual design phase of the design process. Morphological charts and General Morphological analysis (GMA), are based on the pioneer work by Fritz Zwicky 1948), was developed as a method for structuring and investigating the total set of relationships contained in multi-dimensional, non-quantifiable, problem complexes (Ritchey 2010). An introduction to General Morphological Analysis as well as its history and some applications is given by Ritchey (2010).

The morphological approach has several advantages over less structured approaches. It seeks to be integrative and to help discover new relationships or configurations (Ritchey 2004). Importantly, it encourages the identification and investigation of boundary conditions, i.e. the limits and extremes of different parameters within the problem/solution space. The method also has definite advantages for communication and – notably – for group work (Ritchey 2004) It was Norris (1963) who first introduced the application of the morphological approach into the domain of engineering design methods. After that it became a popular tool to generate alternatives.

As stated by Lloyd (1995) there are many methods of investigating the design process and each has salient features: "Interviews, retrospective reports, concurrent reports, teaching, and introspection all have something to contribute to an empirical understanding of the design process. What one should then look for is consistency in the results that each method offers." The use of Morphological Overviews as a prescriptive design tool and as a reflective instrument as such offers consistency.

Here a descriptive element in the design process is introduced by us by using the morphological overview as a tool for visualization of the interaction within the design team. This approach is strongly related to the designer interaction model of de Vries (1994), see Fig. 1.

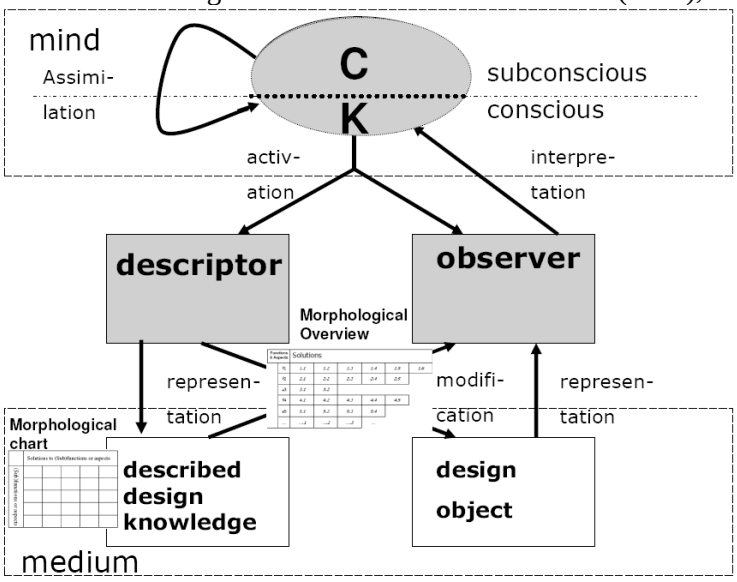

Figure 1. Extended designer interaction model with the morphological overview.

Normally by using morphological charts each designer can look for all the necessary functions and aspects decomposed from the program of demands and the related possible part solutions. We now used it the other way around by using it to describe the design process.

The design session was video recorded, see Fig. 2 and every 5 minutes photos were taken. There was no further intervention in the actual process. The average age of the participants was around 42 years with on average more than 15 year experience. They are all well renowned experts in their disciplines. The structural engineer left the design session at the middle of the session.

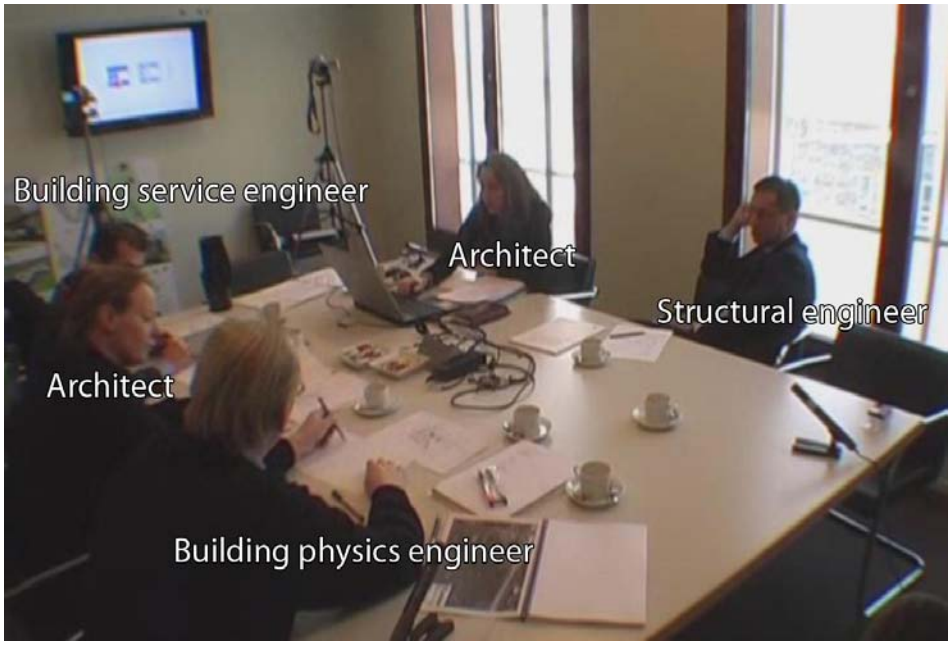

Figure 2. Design team session in preparation to a design competition presentation

The session were analyzed with a special focus on four criteria:

- Aspects which have to be taken into account
- Functions of the buildings presented
- Solutions to these functions

- The number of times the participant participated in the session

All actions were analysed based on time slots of 1 minute. Within the activity slots we looked at whether the participant presented an aspect, function, solution, question, and answer or just participated in the discussion. The actions related to first three criteria are split into verbal activities or sketching activities.

3. RESULTS

Every 5 minutes or at moment of special activity photos were taken, some examples are shown below, see Fig. 3. The photos are helpful to focuss on specific actions and such help the analysis of the video tapes.

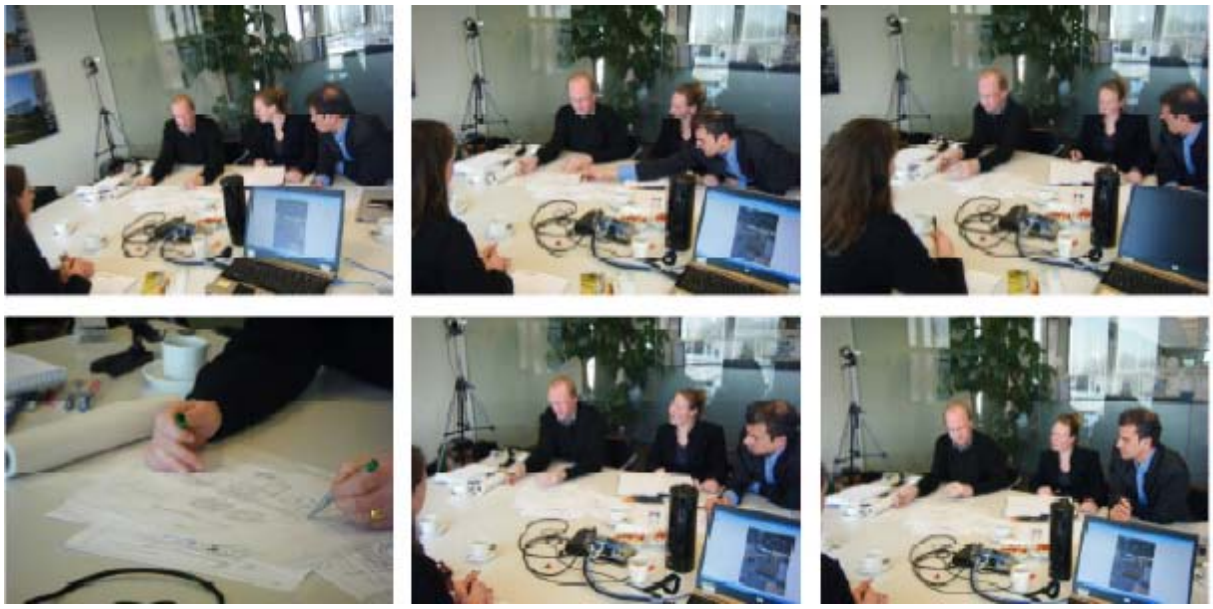

Figure 3. Photographs of the design session

TRANSCRIPT

First an overview of the session is given by making a functional transcript after which the results of the functional transcript are transformed to a morphological overview of the session.

Here only the transcript of the first part of the conceptual design session is given as illustration of the applied method, see Fig.4. The transcript is not a complete transcription of everything what was said but a reduced representation of those remarks that seemed to be relevant for the design process. This reduces the amount of work involved in the analysis. The abbreviations used for the person who mentioned the aspect or solution are the following,

- A1 = Architect 1, leading project architect
- A2 = Architect 2
- BS = Building Services Consultant
- BP = Building Physics Consultant
- SE = Structural Engineer

Interval	Session ID											
0:01:00	By					Type						
Time (min)	Bs	A1	A2	Se	Bp	F	S	D	Q	P	A	Subject/remarks
0:00:00					x			x				"= chit chat
0:01:00	x			x	x			x				
0:02:00			x	x				x				F=Function, S=Solution, D=Discussion, Q=Question, P=Presenting, A=Answering
0:03:00		x		x	x			x				Bs=Building services, A1=Principle architect, A2= Secondary architect, Se=Strucutral engineer
0:04:00	x	x		x	x			x				Bp=Building physics engineer
0:05:00	x	x	x	x	x			x				
0:06:00	x	x	x	x				x				
0:07:00		x			1				x	x	1	
0:08:00	2	x	1						x2	x	x1	A1 comments that the project cannot be built whitin the given budget
0:09:00		x								x		
0:10:00		x		1	2				x21	x	x12	
0:11:00	1	x							1	x	x	A1 advices everyone to read the give documentation
0:12:00	1	x							1	x	x	A1 Contract cannot be insured on all points
0:13:00		x	2		1				1	x	x2	
0:14:00		x	2	3	1			x123	1		2	Discussion on whether the mentioned weight factors will be taken into account as mentioned
0:15:00		1		x						1	x	How to present their concept to the client
0:16:00		x						A		x		
0:17:00		x			1				1		x	Discusion about the fee for each participant
0:18:00		x		1				A	1		x	Se has questions regaring the competitiors
0:19:00		x								x		The terrain is presented
0:20:00		x								x		A1 announce that there is no urban planning plan for the area
0:21:00		x	2		1	1			1	x	x2	A1 mentions sound as a problem due to the local train station
0:22:00			1	3	2				23	1	1	Bp has questions about Surface water drainage
0:23:00	2	x	1						2	1	1x	
0:24:00		x	2		1			A	1	x1	2x	Se ask whether they want a vision or plan presntation, A2 answers vision
0:25:00		x						A		x		A1 presents what is expected from Se, Bs and Bp during the presentation to the principle
0:26:00		x								x		A1 presents the sketch desings made sofar
0:27:00		x								x		A1 thinks emotion is more important in the presentation then the solutions
0:28:00		x				x				x		The building must be able to grow (3 concpets presented)
0:29:00		x	1							x1		The presented sketches have rough dimensions attached
0:30:00		x	1	2		2			2	1	x	Se ask whether the building must be able to grow and shrink, A1 answers both is preferable
0:31:00		x			1	x			1		x	Bp what about sustainabiliy, A1 Sustainable whitin budget
0:32:00		x					x			x		Sustainable through design
0:33:00		x			1		x		1	x		Sound reduction through design , Bp ask if fresh schools is a function
0:34:00		x		2	1		1	x	2		1	What is a fresh school, Answer Temperature control and ventilation
0:35:00	x				1		x1	x				Bp use a mix of diiferent ventilation concpets, Bs control ventilation based on occuoancy
0:36:00		x				x		x		x		Reduction sound pollution is a function
0:37:00		x						x				
0:38:00		x								x		Bp sketching
0:39:00		x	1							x1		
0:40:00		x		1	2		x1	x1	21		x	All education tools with large weight are to be located on the bottom floor
0:41:00					1		1					Model solution options
0:42:00								A				Is it advisable to focus on details?
0:43:00					1			A				Schools have become introvert should we focus on making this one extrovert
0:44:00		x	1		2			A				
0:45:00		x			1	x		A				Design with costs in mind, Bp keep the installations simple
0:46:00		x								x		
0:47:00		x	1	2	3			A		x1		
0:48:00		x	1	2				2		x1		
0:49:00		x		1				x1				Se translate sustainable solution into leyman terms
0:50:00	1	2	3	4	5			A				
0:51:00		x		2	1				12		x	Disucssion on what is needed from each for the final presentation
0:52:00		x			1			A	1		x	Only over what is asked and not what they think is needed
												Einde Deel 1

Figure 4. Functional transcript of the first part of the conceptual design session (Norrby 2010).

MORPHOLOGICAL OVERVIEW

From the functional transcript a morphological overview was derived which represents a first left column with the aspects/functions mentioned during the design session and the mentioned sub solutions related to the function/aspects put behind in different connected rows, see Fig. 5.

Source function or solution							
Architect 1	Architect 2	Structual engineer	Building services	Building physics	Principle		
Morphological overview							
Functions	**Solutions**						
Cost	Building design	Heavy devices on ground floor	Keep the installation simple	Dubble functions	Mix balanced en mechanical suctions ventilation	Modulair ventilation design	Control on occupancy	Atrium should get air from the class rooms
Limit sound pollution	Building design							
Vision	Dubbel fucntions	Building orientation	Building design	Extrovert				
Innovation	Building design	Building orientation	Modulair ventilation design					
Growth/Shrink	Building design							
Sustainable	Building orientation	Control on occuopancy	Light dooms	Atrium should get air from the class rooms	Daylight intensity lightning control			
Fresh schools	Mix balanced en mechanical suctions ventilation	Atrium should get air from the class rooms						
Overzicht op de leerlingen	Building design							
Limit voyuerism	No balustrades							
Exterior should not look like a school	Building design							
Surface area	Building design							
Co-operation	Building design							

Figure 5. Morphological Overview of the conceptual design process based on the transcript of the design sessions (Norrby 2010).

ANALYSIS

The photos were quite useful in combination with the video recording to focus on specific moments or details. The data is based on the functional transcript of the video recordings. Functional transcript summation is given in table 1:

Discipline Designer	Aspects		Functions		Solutions		Participation count		
	Verbal	Sketch	Verbal	Sketch	Verbal	Sketch	Session 1	Session 2	Total
Building services	0	0	1	0	6	0	10	18	28
Architect 1	5	3	5	0	4	0	45	18	63
Architect 2	1	0	0	0	0	0	17	13	30
Structural Engineer	1	0	1	0	1	0	19	0	19
Building Physics	4	1	4	0	9	0	26	24	50

Table 1. Results of the transcript (Norrby 2010).

To get a clearer picture the first six columns are presented in a pie chart, see Fig. 6. The participation count is dealt with separately. To make it more suitable for drawing conclusions some more overviews are given which give a better insight into the distribution of the inputs of the team members. If this is spilt into Verbal versus Sketch the following balance is attained.

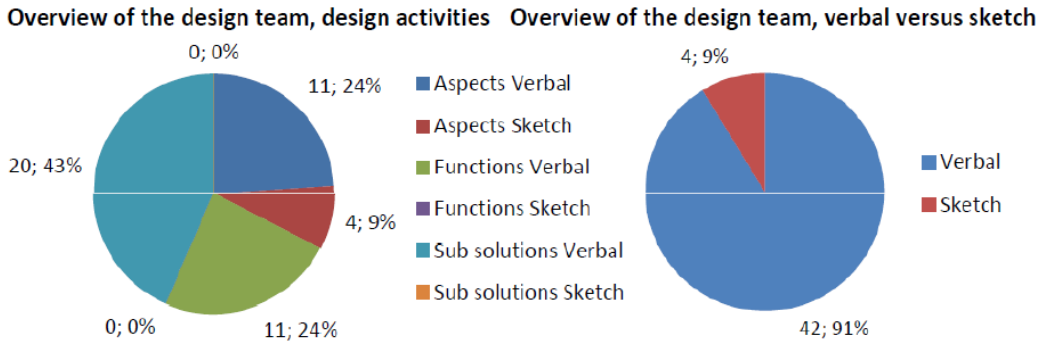

Figure 6. Overviewa of the design team activities (Norrby 2010)

This shows that the group preferred verbal communication then sketching solutions. The analysis of participation distribution of the individual designers leads to the following overview, see Fig. 7.

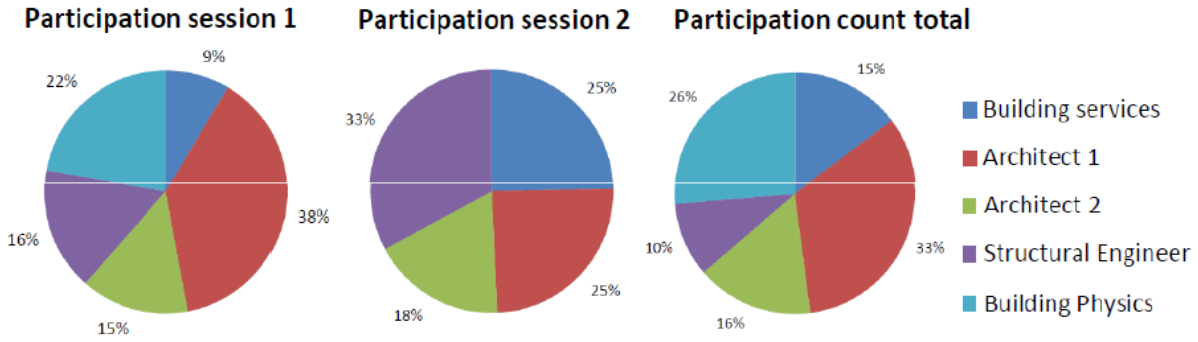

Figure 7. Participation by the different designers during the design sessions (Norrby 2010)

From this follows that in the first session the leading architect (architect 1) clearly has the lead since this is the phase in which the project is introduced and their first design concepts are presented. The second architect assisted the leading architect when there where questions regarding specific aspects. The building services engineer was the most passive person during the presentation phase. During the first session aspects, functions and solutions were also discussed but the focus was on the introduction of the design task and the presentation ot the first ideas from the architects. After the presentation

phase the structural engineer had to leave. The second session was more design focused and discipline based, which can be concluded as the contributions of the participants were more in balance with each other. This seems to indicate that they are willing to listen to each other and were not passive in the process of getting involved and actively discussing with each other the different aspects and viewpoints of each discipline. The input by the individual participant per category during the whole process is given in an overview, see Fig. 8.

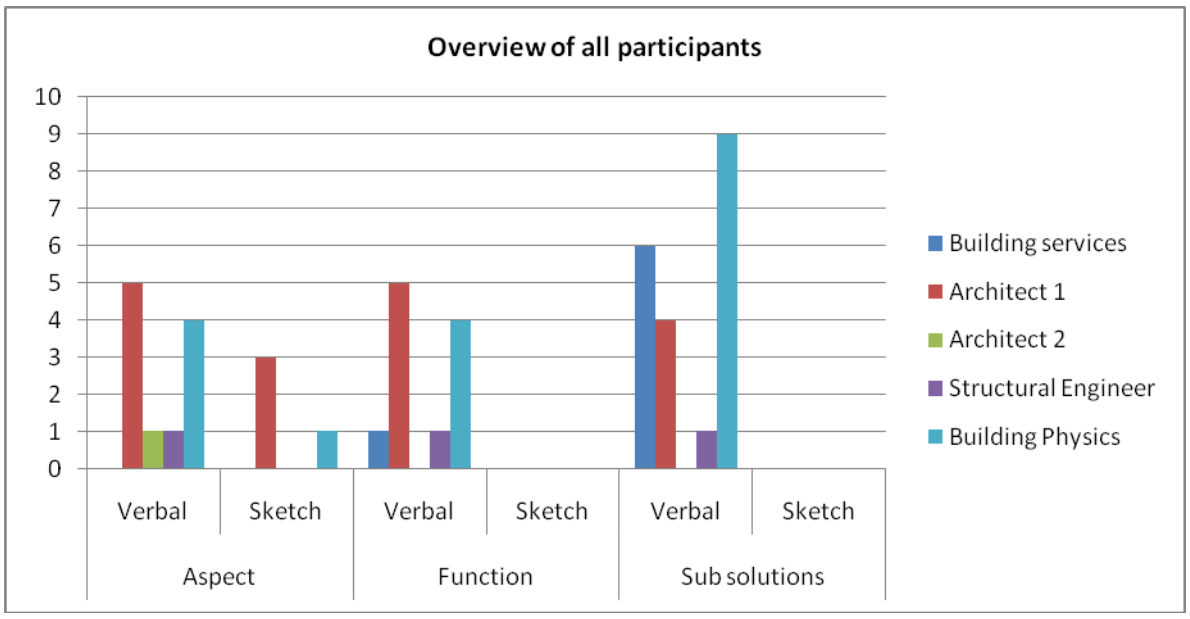

Figure 8. Amount of input by the different participants during the whole design session (Norrby 2010)

This shows that on an individual basis the building physics engineer and the leading architect are active in the total design process. The second architect is more passive in the design process. The building services engineer is more solution oriented and seems to stick to his speciality. The structural engineer is difficult to compare since he left the session half way into the process. This conclusion seems to be backed up by the overall count of participation actions, with the exception of the second architect, who participates but does not give aspects, functions or solutions in balance to her participation level, see Fig. 9.

Aspects

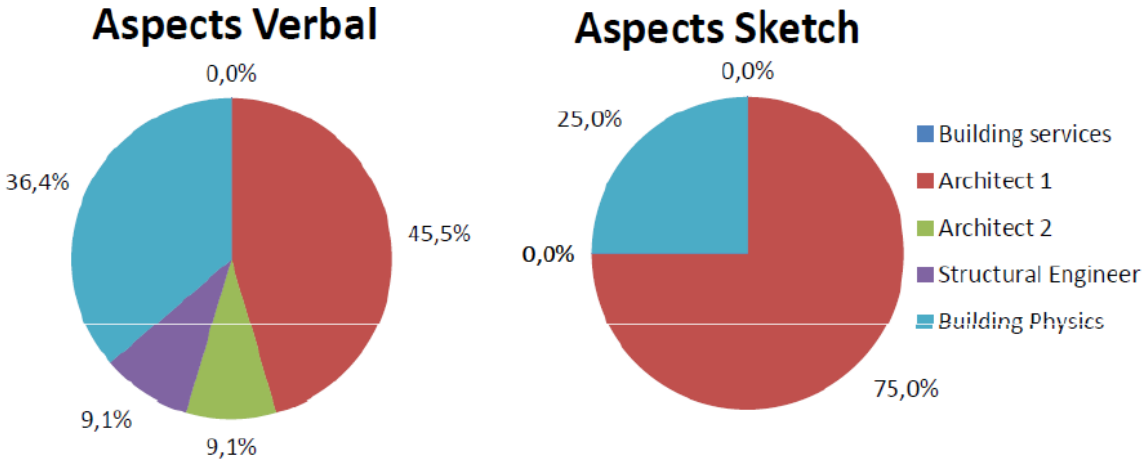

Figure 9. Comparison aspects verbal and sketch by each designer (Norrby 2010)

The imbalance between verbal and sketch is shown here in Fig. 11 for the individual disciplines. As expected the architects contribute more by sketch than verbal.

Functions & Solutions

Here again, see Fig. 10, it shows that the main participants are the building physics engineer and the principle architect. The structural engineer and building services engineer give some input, while the secondary architect is passive. The secondary architect is passive in putting forward solutions. The structural engineer gives a few solutions but was not present in the second part of the design session which was more focussed on the solutions. The building services engineer is here more active since his speciality is more involved. However the most active is the building physics engineer. The principle architect participates but is less active probably waiting for the input from the specialists.
The two design sessions used a rather unstructured approach. The 'chair' of the session, the main architect, had prepared the session to first be a presentation of the assignment and then their preliminary conceptual designs. There was an attempt to present the concepts on different levels to determine how to present their vision on the solution of the given design brief.

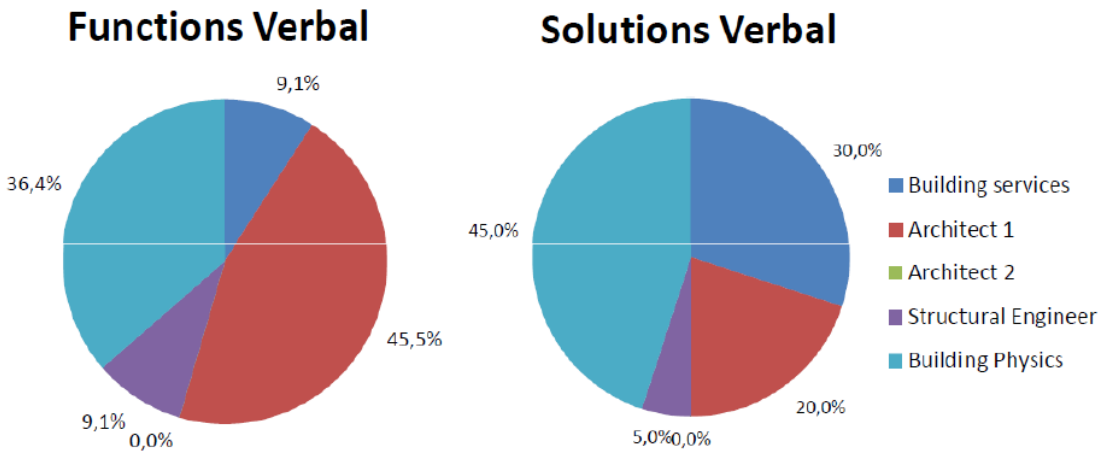

Figure 10. Comparison functions and solutions verbally by each designer (Norrby 2010)

6. CONCLUDING REMARKS

Making a functional transcript and morphological overview of the design meeting definitely gives a better understanding of the design process. Because by writing down all mentioned aspects and solutions, one can make a very useful overview and summary of the meeting. The information and ideas can then be structured in a clear form, which can be used later on in the design process, by all participants. During the design process itself it was very clear that the architects had the most input in the meeting. They were the people who lead the team and were better informed about the assignment. And from the other three consultants the building physics consultant was much more actively involved during the meeting than the other two. The building physics consultant was actively involved in most aspects, whereas the structural engineer and building services consultant stuck very much to their own discipline. As a result the amount of input from the different participants was very different. This all becomes very clear when one looks at the various charts.

Furthermore there are several other things to be noted. For instance, sketches were only made by the architects, the input of the other three members was only verbally. And when looking at the last chart, which gives a total overview of the number of contributions per input type, it is also very obvious that the meeting resulted in many sub-solution compared to general solutions.

During this design meeting only some of the solutions of the architects were sketched. All the other generated solutions were only verbally mentioned and explained. More drawings and sketches would be more useful and clear for the design process and meetings in the future. Furthermore, the visual documentation of the session was mainly focused on the presentation of the architects. So when the participants had a remark or idea it could only be observed by hearing, small sketches and things that where pointed out were hard to notice.

Our results show that morphological charts are useful for the analysis of design meetings as they were being capable of presenting the development of design concepts. Morphological charts proved to be effective in reducing the time needed to analyze a rich set of data. We believe this complexity reduction offers the possibility of doing research on more (complex) design meetings more effectively, which is beneficial for generalization of findings.

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