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INTEGRAL BUILDING DESIGN APPROACH IN MULTIDISCIPLINARY TEAMS

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1. Introduction of the sustainable comfort context

There is a persistent discrepancy between increasing demands for comfort in buildings and the need to decrease the use of energy. It is the design team that has to deliver solutions for this kind of contradictions during the creation of building designs. However, the building design processes themselves cause some of the flaws and additional costs that accompany many building projects. The important aspects herein are:

1. the most important decisions are made during the conceptual phase of design, even though not all relevant information is available then [SBR 2001];
2. some relevant disciplines are involved too late in the process [Zeiler et al.2005];
3. as the complexity and scale of design processes of buildings increases, the traditional approaches no longer suffices [Van Aken 2005];
4. cooperation between design disciplines is unsatisfactory; better organization of the design process is necessary [Friedl 2001].

By using sustainable energy in comfort systems for heating, ventilation, air-conditioning and lighting, the focus on the negative effects of energy use, about 40% of which is caused by the creation of thermal comfort in buildings, can be turned to comfort again. Still, the application of sustainable comfort systems in the early stages of building design is currently too low.

Looking at comfort from other viewpoints one could say that comfort is achievable without use of any systems at all, or at least by their limited use. To achieve comfort through design properties of the building as an object, in which there is no need for additional 'mechanisms' to compensate the aspects that are left aside during the conceptual phase of designing, integrated architectural solutions that already have various comfort aspects incorporated in them need to be developed. The application of the view that designing is the most central activity in engineering [Krick 1967] should help to overcome the difficult current situation where the present artificial separation between 'design' and 'specialist' activities (architects vs. various advisers) hampers teamwork between various disciplines. A design methodology that provides a suitable foundation for improvement of integration needs to be defined and tested. It concerns building design team activities integration as well as integration of sustainable comfort aspects during the conceptual phase of design process.

1.1 Design team approach

Integral design solutions are only possible through unification of different viewpoints on the same topic [Dorst 1997]. In order to achieve integration a single designer has to 'force' himself to look from different viewpoints while designing. Even if he proves that he is able to deploy most of the viewpoints that play a role in building design practice, he does not have knowledge to assess all of them. This is the reason to assume that design team's view of design, and not mono-disciplinary view of design, is the only way to pursue design integration. The advantage of design team approach

compared to a single designer multi-approach is that different design team members and disciplines already represent different views on same topic. To get all design disciplines together at the beginning of design process, a designers' working environment in form of workshops was created. Workshops are seen as a self-evident, although not predominant way of working for designers that occurs both in practice as during their education. This essentially artificial work environment is, therefore, not as such experienced by designers themselves. Other advantages the workshops have regarding standard office situations are: full control of design team composition, possibility to gather a large number of professionals in a relatively short time, openness of participants for new methods, repetition of same assignments and comparison of design teams and their results.

The framework for structuring actions of team members is found in 'Methodical design' [vd Kroonenberg and Siers 1992], a model which is problem oriented and distinguishes, based on functional hierarchy, various abstractions and/or complexity levels during different design stages and design phase activities. This framework that proved to be successful within mechanical engineering domain [Blessing 1994], and which makes it possible to explicitly think and act on one specific abstraction level, needs to be adjusted for use in design teams within building design domain.

Through use of workshops a support for integral design processes can be developed without interference of various constraints that actual projects in practice have. Within this 'learning by doing' approach design process models are applied, tested and evaluated while professionally qualified designers carry out several design assignments in repeated series of design sessions. This paper will show initial workshop results, focusing on communication between design team members and on use of morphological overviews (as a methodical design tool). Through combined evaluation of these aspects further steps in description-prescription-description cycle, which is used as research methodology [Blessing 1994], will be presented.

2. Workshops as a research and development tool

2.1 Definitions

The pursuit of design (activities) integration is based on integral approach as defined by [Quanjel and Zeiler 2003]. According to them integral approach "…represents a broad view on the world around us that continuously needs to be adapted and developed from sound and documented experiences that emerge out of interaction between practice, research and education…".

The emphasis on involvement of true design disciplines forms the starting point for integral design process organization. This on the contrary of design process organization types where the role of managers, clients and/or constructors (which, generally speaking, do not posses design capabilities) often tends to somehow overshadow, and sometimes even dictate in/output from the designers.

The first result of integral approach is a definition of building design team that should incorporate an architect, a structural engineer, a building physics consultant and a building services consultant.

The sequential involvement of design disciplines during traditional design process is something that hampers the development of integral design methodology, and, as such, needs to be addressed. By doing this, the second listed aspect that causes flaws and additional costs, a too late involvement of some relevant disciplines during building design processes, is taken into consideration. Making sure that all design disciplines start working on design task directly at the beginning of conceptual design phase assures input of relevant design knowledge. The conceptual phase of integral design process is thereby partly defined as a period in which building design team disciplines are synchronously involved in process of designing. Synchronous communication is the communication between senders and receivers at the same time, whether or not at the same place. In case of workshops the synchronous communication is always applied 'at the same place'.

In order to structure knowledge and viewpoints of design team disciplines, use of morphological overviews is encouraged during the workshops. Morphological overviews are one of the features of Methodical design, and are used to present an overview of available 'field of possibilities'. Their application leads to exploration of more solution proposals. This method uses a morphological chart, in which main design task is interpreted as a set of functions and/or aspects. For each of these defined

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(sub) functions/aspects a variety of possible solutions is generated. Consequently, coherent unification of produced sub solutions can lead to an overall integral design solution proposal.

2.2 Set-up

The workshops are organized in cooperation with the Royal Institute of Dutch Architects (BNA), the Dutch Association of Consulting Engineers (ONRI) and the Knowledge Centre Buildings and Systems, the cooperation between Eindhoven University of Technology and the Netherlands Organisation for Applied Scientific Research (TNO). The workshops consist of three half-day sessions that take place once a week, on a same weekday. This configuration is the result of experiences gained in previous workshop tryouts during year 2001 and 2002 [Quanjel and Zeiler 2003], involving more than 200 professionals. In year 2005 two workshop series were organised, the first on 31 May, 7 and 14 June, and the second on 24, 31 October and 7 November.

The first workshop day during both series was used as a team building session and as training for use of methodical design aspects. The design teams' formation was random, meaning that no pre-selection took place. Moreover, mirroring common situation from daily practice, none of the participants worked together before. The crucial aspect for learning in a team configuration is creation of a shared understanding [Mulder and Swaak 2002]. This is mostly a slow process that is often based on social aspects of interaction between team members. To avoid one other common practice situation, where the purpose of 'workshop-like' meetings is just to get better acquainted with each other, all teams were asked to directly proceed with work on the presented design task. Morphological overviews were thereby used to structure this accelerated design process. Because the basic principle of the workshop set-up was to avoid a 'laboratory situation', design teams were not 'forced' to use morphological overviews. However, they were instructed how to do it, after which a design assignment was presented that had to be worked out in 90 minutes for a short presentation. The same assignment, to design a small 'pavilion for sustainable architecture' on the building the workshops were taking place in, was given to all design teams during both workshop series. Following assignment presentation, design process was only observed and no further intervention took place. At the end of the first half-day all teams gave short presentations of their produced conceptual ideas.

During the second day the same design teams were given larger design assignment. The task was to design a zero-energy multifunctional office building on a 'standard location'. The focus was on generation of solutions, as anticipated by different disciplines, using morphological overviews. In contrast to the first day, at the end of the second day the teams did not have to present their results. Instead, the whole 120-minutes of design session were used for generation of possible solutions.

During the last day the design teams had to integrate generated (sub) solutions into an integral office building design. The team's generation and integration of possibilities are, in general, achieved through communication. This aspect of the use of morphological overviews can be consciously experienced only during the communication with someone that stands outside design team itself. Therefore, before making final design choices all teams had to report to the client what the status of their designs was. Using same morphological overviews design process was transparently presented to the client. During the first workshop series the client role was 'played' by a representative from the ONRI and during the second series by a representative from the BNA organisation. Besides the feedback to the 'client' all design team had to present their final integral design solutions to each other. During short presentations, both on the first and on the final day, the participants rated each other. They did not, however, rate the results of their own design team.

2.2.1 Design teams

The design teams consisted of professionals who applied via their respective organisations, BNA and ONRI, to participate in the workshop series. The intention was to have several complete design teams whose composition ideally should not change. This situation was not always achieved during the workshop series, as we will discover further on in the text, something that also in practice is mainly not the case. Therefore, a provision was made that others from the same field could replace the particular representatives of the four design team disciplines, which indeed occurred several times. The number of representatives from the same discipline was also seen as irrelevant; only the presence

of the discipline itself was desirable. During both workshop series the teams changed no more than two members at the same time.

In the first workshop series 24 professionals participated: 5 architects, 6 structural engineers, 5 building physics consultants and 8 building services consultants. During the whole series two teams consisted of all four desired disciplines, while other two were missing structural engineer for one day.

In the second workshop series 19 professionals participated: 6 architects, 1 structural engineer, 5 building physics consultants and 6 building services consultants. An additional participant was one manager, a discipline that is not seen as design oriented. However, this way we could compare the course of design process in the team with the manager versus the teams without one. A problem was posed by the general absence of structural engineers, because of which only one team was identical to the teams from the first workshop series. And even this team had to miss its building physics adviser on the last day. Because of the described situation the intended joint evaluation of the results from both workshop series could not be done. Instead, the two workshops series were compared.

Table 1. Design teams line-ups (A=architect, B=building physics consultant, BM=manager, C=structural engineer, K=building services consultant); in bold are the team members that did not change during the 3-day course

Day	1st workshop series					2nd workshop series				
	Team A1	Team A2	Team A3	Team A4	Team A5	Team B1	Team B2	Team B3	Team B4	Team B5
1	**AB-K**	ABCK	**ABCK**	**ABCK**	ABCKK	ABCK	**AB-K**	AB-KK	**AB**BM**K**	**AB-K**
2	ABCK		**ABCKK**	**ABCK**	ABB-K	ABCK	**AB-K**	AB-K	AB-K	AAB-K
3	ABCK		**ABCKK**	**ABCK**	ABCK	A-CK	**AB-K**	AB-KK	**AB**BM**K**	**AB-K**

The distinction between design teams with four (A3, A4), and design teams with three (B2, B3, B5) desired design disciplines was made. The results section shows differences in design processes between these two design team types. The design teams A1, A5 and B1, which over the course of three workshop days resembled both defined types, were also looked closer at. This has been done in order to see if the changes in their arrangements had any effect on the measured aspects.

Finally, even though there was only one design team (B4) including management discipline, an attempt was made to try to discover if any major differences with the rest of the teams occurred that could possibly demand further (comparative) research.

2.3 Data collection

The important link, and an essential part of the integral approach, between practice, research and education was established during the workshops through involvement of Eindhoven University of Technology (TU/e) students. The students had the role of neutral observers, and were beforehand extensively instructed in order to be able to perform their tasks.

The raw data concerning team communication and use of morphological overviews (for purpose of design and communication) were collected in three different ways:

- direct observations of design processes by the students,
- various questionnaires for the participants, and
- photographically capturing design processes and produced materials.

The type of activity, its occurrence in time and frequency were all registered. Through analysis of all results it was possible to evaluate the effect of the proposed approach. Based on this evaluation the criteria for the next workshop series can be set and the entire iteration cycle can be repeated.

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2.3.1 Direct observations

The direct student observations were carried out differently during the two workshop series. During the first series three students per group were deployed to observe three different aspects of design process. Three things were looked at: communication between different disciplines, individual contribution of separate disciplines and use of morphological overviews. Different students were active during different three half-days, meaning that in total around 40 students were involved in observing different aspects of designing.

During the second workshop series individual contribution was not separately measured because it was found out that the same information can be extracted from observed communication patterns and the actual use of morphological overviews. Both these aspects were this time recorded by one student, with two students being deployed per design team. The same students observed the same teams during the whole duration of second workshop series. The main communication patterns were registered in 10-minute intervals. Observed communication was defined as discipline-to-discipline or team based. Morphological overviews could be used either for introducing design solutions or for communication; in both cases the distinction between reporting and giving/acquiring insight was made.

2.3.2 Questionnaires

Because the amount of integration in the final design proposals could not be measured, it was very important to learn how the designers experienced the proposed approach, and if they thought of it as beneficial. The only way to find out if this was indeed the case was to get first hand information from the participants themselves. For this purpose various questionnaires were used. The participants were also asked to rate each others presentation results, in order to get some indication if the measurement results of the observed design processes match the overall impression one gets of the consequent design processes results. In order to assess if the proposed approach was afterwards also used in daily practice of the participants, some questionnaires were (scheduled to be) repeated after a couple of months.

2.3.3 Photographs

To verify the combined results from student observations and participant questionnaires, the design process was photographically captured with a shot of the work of each group every 10 minutes.

3. Results

During design process the general communication patterns and use of morphological overviews were observed. The results of those observations are shown in table 2. Overall, big differences between the two workshop series can be seen; and the question arises of whether the different design teams' compositions could be the cause for this.

However, two results are very similar: increase of team communication during the three days course and more extensive use of morphological overviews for generation of new design possibilities during the second day.

Table 2. Observation results during 1st and 2nd workshop series

1st and 2nd series comparison			Day 1		Day 2		Day 3		average	
			1st	2nd	1st	2nd	1st	2nd	1st	2nd
Communication	1 on 1	arch ↔ adv	44%	52%	41%	32%	36%	27%	40%	37%
		adv ↔ adv	37%	11%	31%	14%	34%	14%	34%	13%
	Team		19%	37%	28%	55%	30%	59%	26%	50%
Morphological overviews	Design	Report	24%	43%	62%	60%	24%	40%	37%	48%
		Insight	16%	23%	2%	18%	19%	16%	12%	19%
	Comm.	Report	12%	14%	5%	4%	20%	19%	12%	12%
		Insight	48%	20%	31%	18%	37%	25%	39%	21%

Table 3. Comparison between 4-discipline (A's) and 3-discipline (B's) design teams'*- A3 not observed)

A3-A4 vs. B2-B3-B5			Day 1		Day 2		Day 3		average	
			A's	B's	A's	B's	A's	B's	A's	B's
Communication	1 on 1	arch ↔ adv	35%	67%	44%	29%	33%	31%	37%	42%
		adv ↔ adv	42%	11%	34%	12%	34%	16%	37%	13%
	Team		23%	22%	23%	58%	33%	53%	26%	44%
Morphological overviews	Design	Report	22%*	41%	68%	71%	31%	53%	40%	55%
		Insight	0%*	25%	1%	11%	6%	13%	2%	16%
	Comm.	Report	13%*	13%	3%	4%	15%	15%	10%	11%
		Insight	64%*	21%	28%	14%	48%	18%	47%	18%

To investigate the differences between the two workshop series, a comparison was made between design teams that consisted of 4 and those that consisted of 3 design disciplines (table 3). There are a number of interesting observations that can be pointed at. First, the amounts of reporting/archiving (communication-report field) were similar, which means that all teams present their design proposals more or less in the same way. This is something that can be confirmed by the overall observation results (table 2), and could be used as a reference for future workshop observations.

Second, the main difference between the design teams is the extent to which morphological overviews were used for explanatory communication (giving insight), which is bigger within the 4-discipline team configurations. Theoretically this would leave them less time for actual designing, which would lead to less new design insights. An important note here is that insight largely depends on (design) quality of participants, something that was not taken in account, nor was age, difference in experience or any other person-related aspect. However, 4-discipline teams were the most productive.

Third, the amount of team communication is clearly bigger within 3-discipline design teams, suggesting that a mutual understanding is reached faster – theoretically leading to less explanatory communication and more new design insights.

Table 4. Comparison of observations regarding teams with shifting configurations (left columns show the results of 4-discipline and right columns of 3-discipline configurations for each day)

A1-A5-B1 changes			Day 1		Day 2		Day 3		average	
			A5-B1	A1	A1-B1	A5	A1-A5	B1	4-disc	3-disc
Communication	1 on 1	arch ↔ adv	41%	60%	30%	33%	38%	0%	36%	31%
		adv ↔ adv	24%	25%	26%	8%	34%	0%	28%	11%
	Team		35%	15%	45%	59%	27%	100	36%	58%
Morphological overviews	Design	Report	43%	20%	55%	78%	19%	24%	39%	41%
		Insight	8%	29%	8%	0%	30%	22%	15%	17%
	Comm.	Report	14%	15%	8%	22%	19%	34%	14%	24%
		Insight	36%	37%	31%	0%	33%	20%	33%	19%

In order to confirm these suspected relations, an additional evaluation of observation results of the three design teams (A1, A5 and B1) that during the workshop series shifted from 3- to 4-discipline configurations (table 1), and vice versa, was made (table 4). This is actually a favourable situation, which makes it possible to compare if their differences reflect the overall relations between 'standard' 3-discipline and 4-discipline teams. Because these design teams went through different group forming processes than the 'standard' teams, only the ratios and not the absolute results between the observations were compared. On average, it could be confirmed that team communication in 3-discipline design teams is much more intense, including more rapid advancement towards its full implementation during the course of the workshop series. Morphological overviews were used more for communication in 4-discipline design teams, in sense of providing insight to the other team

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members. The amount of reporting/archiving results of design processes differs, however, from the overall observations. It is interesting that this difference originates from 3-discipline design teams. More specifically, the high amount of reporting/archiving on days 2 and 3 were the ones that caused this difference, precisely the moments when team configuration changes occurred. These changes, which did not occur within other teams, could be the explanation for differing results. The addition of manager-team results in evaluation of observations only marginally changes the overall average communication results.

Conducting questionnaires helped to find out more about use of morphological overviews. The importance of proposed approach for daily practice was confirmed by 61% of participants, 29% was in doubt, and 10% thought of it as unimportant. Only 6% of participants considered use of morphological overviews irrelevant for their discipline, and 13% thought that use of overviews was not positive for communication within design team structure. However, the majority was convinced that their use is beneficial for: number of relevant produced alternatives (66% yes-answers with an average rating of 6.8), team design process (7.2), awareness-raising on contribution by other disciplines (7.4) and, of course, communication (7.2). Working within design teams was experienced very positively by 76% of participants, with 7.8 as average rating. The two aspects that were given low ratings were the expected use of morphological overviews in one's own future practice, with only 36% answering 'highly likely', and the effect morphological overviews had on the final design proposals, with less then half (43%) of participants finding it positive.

This last aspect seems to contradict the ratings of mutual team presentations. The best rated design proposals, at the same time also seen as most integrally approached solutions, can indeed be linked with high use of morphological overviews. Without judging their quality, the proposed solutions were also rated for innovativeness of their idea. The lowest ratings, concerning integral approach and innovativeness of the proposed solutions, were given to the manager-team. Innovativeness was defined as possible to achieve by combining existing solutions to a novel design concept. These standard solutions were to be presented using morphological overviews; it was assumed that through interdisciplinary communication they could lead to innovative solution proposals. According to (very) limited comparative results, the presence of building management discipline within a design team does not directly enhance innovative design.

Design process was also photographically captured each 10 minutes. This way the development in time of the amount of proposed alternatives was registered. Through quantitative changes of the amount of proposed alternatives, generation activities of design teams could be followed. The second day was the most important for this type of measurement (use of morphological overviews for generation of solution proposals). The first day was 'only' a training session, while during the third day the focus was on integration of generated proposals. It was observed that both 3- and 4-discipline design teams needed the same amount of time to define the functions/aspects they were going to work on (this lasted between 35-45 minutes). From there on the number of produced alternatives by 4-discipline teams was much bigger then by 3-discipline teams.

4. Conclusions

The first conclusion that can be drawn, based on the two observed workshop series, is that (development of) design team communication is dependent on the number of design disciplines within design team. The 3-discipline design teams develop some kind of mutual understanding and agreement faster than 4-discipline design teams. An additional conclusion is that this is not directly related to the use of morphological overviews for communication purposes. On the contrary, the 4-discipline design teams, which internally communicate more on a 1-on-1 basis, used morphological overviews more frequently for communication purposes. However, the influence of morphological overviews in achieving mutual understanding in 3-discipline teams was not separately assessed.

From the results can be concluded that the overviews are indeed considered helpful in structuring the communication of design teams, especially in more complicated situations. This statement is backed up by the results of the various questionnaires that all participants were given, regardless of discipline or the design team arrangement.

Morphological overviews are also suitable to archive the discussed proposals. The preliminary results show that in 10-15% of the cases they are used for this purpose. This figure will be looked at more closely in the future in the hope that we can confirm it as a reference value. Concerning design aspects of the use of morphological overviews, it is concluded that the overviews are helpful in structuring the design activities of the design teams, and that they can be helpful in widening the field of relevant possibilities. Additionally, based on the reactions from the participants themselves, the morphological overviews are found to be relevant for use in practice: they help in communication within a design team configuration, they increase the number of relevant and new alternatives and they raise the awareness on contribution by other design disciplines. However, the participants pointed out that these positive aspects do not necessarily mean that use of morphological overviews is automatically beneficial for final (integral) design proposals; something that has to be looked at further.

Before continuation of the research and organization of new workshop series some main aspects need to be addressed. A clearer distinction between the four main defined conceptual phases (interpretation, generation, selection and integration) needs to be made in order to be able to more precisely assess use of the morphological overviews. This is also true in relation to communication aspects during those phases. A more direct observation of communication with the client has to be conducted in order to be able to compare internal and external design team communication patterns during integration (and/or selection) phase. Defined functions/aspects and consequently proposed alternatives/solutions by design teams need to be better discerned during observations in order to be able to measure effectiveness of proposed approach.

The proposed integral approach involving use of certain aspects of methodical design has been accepted as relevant by the professionals in building practice; from this point on the focus of further research is on how effective it can be made.

Acknowledgements

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