Morphologic C-K reflection for collaborative building design

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Abstract: Design involves multi-disciplinary design teams to support this highly complex process. A reflective design approach is developed: Integral Design. This design process approach results in transparency of the design steps and the design decisions. We regard the activities which make these changes obvious to an external observer as the core elements of designing (design as process). The results of these activities are combined with the C-K theory by Hatchuel and Weil, which defines design as a process generating co-expansion of two spaces, space of concepts C and space of knowledge K. Within the design process, the prescriptive methodology of Integral Design is used as a framework for reflection on the design process itself by the use Morphological Overviews (MO). Morphology provides a structure to give an overview and to structure the communication and reflection between design team members.

1. INTRODUCTION

During the last years aspects of used technology for comfort and energy control within the building industry became more and more important. Especially investments for heating, cooling, ventilation and electricity installations and their control technology has risen from less than 10% up to now sometimes more than 30% of the overall initial building costs. In special buildings like hospitals the percentage of the building Services
component of the overall initial building costs is even more than 50%. Also the demands to comfort and energy consumption became more and more strict.

As a result of this growing part of building services the complexity of building has increased enormously and as a result of this complexity more and more things go wrong. Within the Dutch building practice present estimated costs of failures are 5-10% of the annual turnover: this means already around 8 billion Euros in such a small country as the Netherlands! Some of these costs, according to various researches, are caused / created during the building design processes. As complexity and scale of design processes of buildings increase, the traditional approaches may no longer suffice (van Aken 2005).

To reduce these failure costs collaboration between different design disciplines involved becomes more and more important as design tasks designers are involved with become increasingly more difficult. During building design processes synergy between the different disciplines involved in the design process is necessary to reach good designs. No longer is it sufficient to just merely solve the problems which arise at the level of detailing on the borderlines of disciplines.

There is a need to view all the different aspects of building design in a more integral way, resulting in an integral approach to building design. This integral approach can lead to an integral process in which the design team with help of the design method can meet all required conditions of the end product.

In the second section we present the Integral Design method. Section 3 presents the theoretical background on the transfer of design knowledge into integral design concepts based on the C/K theory. In section 4 the ‘Educational model’ of workshops is described to test the integral design method and to transfer this method to building design practice. The results are presented in section 5 based on questionnaires held under the participants of the workshops. Section 6 presents discussion about some aspects of the design method and the result of the workshops.

2. METHODOLOGY: INTEGRAL DESIGN

The ‘Integral Design’ project, conducted by the Dutch Society for Building Services (TVVL), BNA and Delft University of Technology (TUD), was initiated to raise awareness for the need to reach synergy between disciplines in building design processes. In contrast to present traditional sequential building design approach, we propose that a building design team should start working on a design task from the very beginning of the preliminary
conceptual design phase. Such building design team should ideally consist of an architect, a structural engineer, a building physics consultant and a building services consultant. However, even though we assume that a multi-discipline design team view on design, instead of a mono-disciplinary view on design, is the way to pursue building (design) integration, simply adding new participants into preliminary design phase could even increase problems. There is a need to structure the design process itself by means of a design method. During early 1970s a prescriptive design model was developed in the Netherlands to teach design to mechanical engineering students at the University of Twente (van den Kroonenberg, 1974). Called the methodical design model, it was based on the combination of the German (Kesselring, Hansen, Roth, Rodenacker, Pahl and Beitz) and the Anglo-American design schools (Asimov, Matousek, Krick) (van den Kroonenberg and Siers, 1992). This in the Netherlands familiar model was extended into an integral design model by Zeiler (1993), because; “it is one of the few models that explicitly distinguishes between stages and activities, and the the only model that emphasis the recurrent execution of the process on every level of complexity ( Blessing 1993, p.1398)”. Especially the horizontal dimension is not strongly represented in other familiar design models and thus tend to be forgotten (Roozenburg and Cross 1991, p. 216); “not so much by its authors (see for instance Pahl and Hubka) but by its users and, above all, its critics, leading to faulty arguments and misinterpretation of the model. ” A distinctive feature of the integral design model is the four-step pattern of activities that form the design basic process cycle, which consists compared to the methodical basic design cycle of an additional selecting step, see figure 1.

![Integral design model](image)

*Figure 1. Four-step pattern of activities that occurs on each level of abstraction within the Integral design matrix.*

The major difference between the integral design and other familiar models is the shaping step, in which the design is 'shaped' in to a lower level of abstraction. The design activities sequence in integral design is: define/generate, analyze/synthesize, evaluate/select, and implement/shape. If compared with familiar models e.g. basic design cycle of Roozenburg and Eekels, 1995 (analysis, synthesis, simulation, evaluation and decision) the difference is in the implementation and shaping of the design into a lower level of abstraction and as such a focus on the connection between the horizontal dimension and the vertical dimension of the design model. The
design process becomes more transparent and this increases the possibility to reach synergy between the different disciplines and/or designers involved in the design process.

An important feature of this model is use of morphological overviews which makes it possible to address client’s needs on higher abstraction levels than the program of requirement. General morphological analysis was developed by Fritz Zwicky (Zwicky & Wilson 1967) as a method for identifying and investigating the total set of possible relationships or configurations contained in a given problem complex (Ritchey 2002). Morphology provides a structure to give an overview of the considered functions and aspects and their solution alternatives. Transforming the program of demands into characteristics for input and output (aspects) and formulation of the different relations between input and output (functions) to fulfil, leads to the construction of a morphological overview, see Figure 2.

Figure 2. The transformation from the program of demands into a morphological overview

Morphological Overviews are essentially tools for information processing, it is not confined to technical problems but can also be used in the development of management systems and in other fields (Pahl, Beitz et al., 2007). As such morphologic overviews can be used by the designers to reflect on the results during the different design process stages.

3. THEORETICAL DESIGN MODEL
The theoretical background on how design knowledge can be transformed into integral design concepts is found in “C-K theory” (Hatchuel and Weil, 2003): the C-K stands for concept-knowledge relation. The C-K theory defines design as the interplay between two interdependent spaces having different structures and logics, a process generating co-expansion of two spaces, space of concepts C and space of knowledge K. The structures of these two spaces determine the core propositions of C-K theory (Hatchuel and Weil, 2007);

- Knowledge. A piece of knowledge is a proposition with a logical status for the designer or the person receiving the design. Irrespective of the way in which this status is fixed, any form of logic, whether it is "standard" or "non standard", is in principle acceptable for a design theory. A set of knowledge is therefore a set of propositions, all of which have a logical status (Hatchuel and Weil, 2002).

- Concept. A concept is a notion or proposition without a logical status: it is impossible to say that a concept, for instance an "oblong living room", is true, false or uncertain. A concept is not "knowledge" [9]. Concepts capture the pragmatic notion of “brief” or “broad specifications” that can be found in innovative design.

- Space K. Contains all established (true) propositions (the available knowledge, existing solutions).

- Space C. Contains “concepts” which are unsurten propositions in K (nor true nor false in K) about some partially unknown set of objects called a C-set.

**The design square of Hatchuel and Weil**

A design concept is a proposition that can not be logically valued in K. Concepts are candidates to be transformed into propositions of K, but are not themselves elements of K (properties of K can however be incorporated into concepts). If a proposition is true in K, it would mean that it already exists and all is known that is needed about it (including its feasibility). Design would then immediately stop. There is no design if there are no concepts. Without the distinction between the expansions of C and K, design disappears or is reduced to mere computation or optimization. The transformations within and between the concept and knowledge spaces are accomplished by the application of four operators, see figure 3 (Hatchuel, Le Masson et al., 2004). The two operators C→C and K→K are internal operators to the concept and knowledge spaces, and are not relevant to the expansion of both. The two operators K→C and C→K cross the Concept-Knowledge domain boundary, and are significant in the sense that they reflect a change in the logical status of the propositions under consideration by the designer (from no logical status to true or false, and vice versa).
Within the integral approach the space $K$ is defined by the initial design knowledge that participants from different disciplines bring into the design team.

Only explicitly presented / communicated object design knowledge within a design team is considered and our focus is on how this explicit object design knowledge is transformed / integrated within a multi-disciplinary design team setting. The relation to the design square of Hatchuel and Weil (2003), which consists of four types of transformations that take place within and between the concept and knowledge spaces, and the integral design process is explained step by step in the following section.

**Connection from C-K to Integral Design**

Functions are ‘design team subjective’ descriptions of aspects that the design has to fulfil, meaning that all individual proposals by a designer must be agreed on by the others designers within the design team. Therefore interpretation as an ‘extra’ step is necessary since (beforehand) objective
A definition of design criteria to be met isn’t possible, see figure 4. (Sub)solutions are seen as ‘chunks’ of “object design knowledge” (Hatchuel, Le Masson et al., 2004), which are mainly discipline based. Morphological overviews show the initially available explicit knowledge within a design team, see figure 5. Making object design knowledge explicit enables designers to use it for the creation of design concepts. What we want to look into is whether these concepts are integral (ID) or just plain combinations (RE). It is important to understand that integration of initially presented discipline based design object knowledge is something different than plain combination of sub-results. Combination can only lead to redesign (RE), while concept integration involves transformation of design knowledge. Contrary to redesign, the connections design team (members) make between sub-solutions in order to produce ID-concepts are subjective and design task context dependent.

1 interpreting & 2 generating

Using morphological overviews as a tool, others’ contributions activate individual interpretation, the reflection of a designer, based on which he or she can make the decision to also make an explicit contribution (see Figure 5, symbol 2). Since the object of design is used as the reference, this knowledge is further specified as initial object design knowledge (Figure 5, symbol 2). From these contributions new combinations can occur, (Figure 5,
symbol 3). By utilizing morphological overviews in this way, a reflective step is introduced within the design process, forcing reflection between individual designers and making actual reflection-in-action on a design team level possible. Thus rational problem solving is integrated with reflective practice. The reflection within the integral design method represents potential for the creation of new object design knowledge through the integration of discipline based explicit object design knowledge into integral design concepts (Figure , symbol 3’). These integral design concepts are not merely a variation or combination of existing solutions but have some completely new element or characteristic not found before, (see the ? symbol in Figure 5).

![Diagram](image)

Figure 5. Morphological overviews show the initially available object design knowledge

Concepts acquired by only combining (sub) solutions are regarded as redesigns. Although a given combination might take all relevant aspects (defined by design team itself) into account, it doesn’t represent an integral solution. See step 3 - combining [activities] in figure 6.
Working out specific functions/solutions on a lower abstraction levels, optimize chosen redesigns will gradually lead to detailed solutions (shaping phase). These are again new iODK, only on different abstraction level. Through their transformation/integration ID’s and nODK emerges. See step 4 - optimizing [activities] in figure 7.

Concepts acquired through transformation of iODK are regarded as integral concepts. This is a result of so-called designer’s ‘creative leap’, triggered by (aspects of) presented (sub) solutions and their possible connections. [implicit knowledge is regarded as the other catalyst]. See step 3' - transforming [activities] in figure 6. Through evaluation of ID-concepts, new object design knowledge emerges (C-K theory) since iODK is not sufficient for explanation. This nODK represents potential for creation of innovative design solutions. See figure 7 step 4' - evaluating [activities].

“A concept not being true or false (within space K), the design process aims to transform this concept and will necessarily transform K” (Hatchuel and Weil, 2003, p.6). During the processes of generation and integration of concepts, transformation of the within design team existing object design knowledge into integral design concepts takes place, offering design team members the possibility to acquire new knowledge. However, in order to realize the potential for the creation of new object design knowledge a
A separate evaluation step is needed (Figure 7); something that does not customary happen in building projects. This is the reason why the extension of methodical design into integral design is important, to make the evaluation step explicit.

**4 selecting & 4’ evaluation**

Figure 7. Design process steps 4 and 4’, optimizing and evaluating activities

### 3.3 Resume Design Method

Making object design knowledge explicit enables designers to use it for the creation of design concepts. Integral design concepts (IDC) and plain combinations (RE) are distinguished. It is important to stress that integration of initially presented discipline-based-design-object-knowledge is something different to the plain combination of (sub) solutions. Whereas combination can only lead to redesign (RE), concept integration involves transformation of design knowledge. The actual representations of the discipline-based object design knowledge are considered to be (sub) solutions to a design task, which are proposed in order to define and/or change the object being designed. The (sub) solutions are the result of individual / discipline-based generation activity, and are the answers to the defined functionalities that a
design has to fulfil. The focus is on the possibility of expanding the concept space with integral design concepts (Figure 8, ID), in order to produce potential for creation of new object design knowledge (Figure 8, nODK). From a standpoint that a concept not being true or false (within space K), the design process aims to transform this concept and will necessarily transform K (Hatchuel and Weil, 2003). At the end of the process of generation and integration of concepts, transformation of existing object design knowledge within the design team into integral design concepts takes place, offering design team members the possibility to acquire new insights. In figure 8 the overall design process of integral design and the steps within the C-K process schema are given resulting in either knowledge transfer or knowledge creation.

![Diagram](image)

**Figure 8.** Combination vs. transformation, knowledge transfer vs. knowledge creation

4. **WORKSHOPS TO TEST THE USE OF MORPHOLOGICAL OVERVIEWS**

To test and analyse what the effect of the use of Morphological Overviews is on knowledge transfer and knowledge creation during design processes different workshops series with professionals where held. Since
2005 together with the Dutch Royal society of architects (BNA) and the Dutch Association of Consulting Engineers (ONRI) we organized 5 series of workshops with experienced professionals from both organisations who voluntarily applied to participate. The setting of the workshops chosen is influenced by the concept of Reflective Practice by Schön (1983). Schön (1987) has proposed a practicum as a means to ‘test’ design(ing). Where a practicum is: ” a virtual world, relatively free of the pressures, distractions, and risks of the real one, to which, nevertheless, it refers (Schön, 1987,, p.37)”. In Schön’s practicum a person or a team of persons has to carry out the design. A practicum can assess a design method and the degree to which it fits human cognitive and psychological attributes (Frey and Dym, 2006). Crucial is the simulation of the ‘typical’ design situation. A workshop can be seen as a specific kind of practicum. It is a self-evident way of working for designers that occurs both in practice as during their education. As such a workshop provides a suitable environment for testing the approach. Besides full design team line-up there are a number of other advantages of workshops with regard to standard office situations, while at the same time retaining practice-like situation as much as possible. Workshops make it possible to gather a large number of professionals in a relatively short time, repetition of the same assignment and comparison of different design teams and their results. The workshops are a virtual world; “contexts for experiment within which practitioners can suspend or control some of everyday impediments to rigorous reflection-in-action (Schön, 1983, p. 162).

The participants of each discipline were randomly assigned to design teams, which ideally would consist of one architect, one building physics consultant, one building services consultant and one structural engineer. The integral design method workshops have evolved to a two-day series, see figure 9. The first series we used observers to look at different aspects during the design process and in the last series we used video to record the design team’s process.
In the current configuration (Figure 9) stepwise changes to the traditional building design process are introduced. Starting with the traditional sequential approach during the first two design sessions on day 1, which provide reference values for effectiveness of ‘ID-methodology’ (amount of integral design concepts), the perceived “integral approach” is reached through phased introduction of two major changes: (1) all disciplines start working simultaneously within a design team setting from the very beginning of the conceptual design phase, (2) methodical design model / morphological overviews are applied.

The second design setting allows simultaneous involvement of all design disciplines on a design task, aiming to influence the amount of considered design functions/aspects. Additional application of morphological overviews during the third setting demonstrates the effect of transparent structuring of design functions/aspects on the amount of generated (sub) solution proposals. Additionally, the third setting provides the possibility of one full learning cycle regarding the use of morphological overviews. It concerns an individual, rather than collective/team learning cycle, because in order to be able to effectively apply a new approach, one has to first understand it and make it his own (Jones, 1992).
5. RESULTS

Over the past four years the above described approach was tested in a series of 5 workshops, these typically include around twenty participants and lasted for two or three days. A total of 107 designers participated in a four workshop series, in which 74% of the designers were present during all days. The average age of the participants, all members of either BNA or ONRI was 42 and they had on average 12 years of professional experience. Direct at the end of the workshop the participants were asked to fill in a questionnaire in which questions were asked about the importance of the use of morphological overviews within the design process and about the concept of the workshops themselves. The participants were asked to fill a questionnaire and had to rate the answers, the average results was then transformed to a rating between 1 (very poor) to 10 (excellent), see table 1.

<table>
<thead>
<tr>
<th></th>
<th>series 1</th>
<th>series 2</th>
<th>series 3</th>
<th>series 4</th>
<th>series 5</th>
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<tbody>
<tr>
<td>Number participants</td>
<td>20</td>
<td>20</td>
<td>22</td>
<td>27</td>
<td>18</td>
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<tr>
<td>Percentage returned questionnaires</td>
<td>88%</td>
<td>96%</td>
<td>98%</td>
<td>96%</td>
<td>97%</td>
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<tr>
<td>MO increases relevant alternatives</td>
<td>6.2</td>
<td>7.3</td>
<td>5.7</td>
<td>7.8</td>
<td>7.9</td>
</tr>
<tr>
<td>MO improves insight other disciplines</td>
<td>7.4</td>
<td>7.4</td>
<td>5.6</td>
<td>7.7</td>
<td>8.5</td>
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<tr>
<td>MO relevant for own discipline</td>
<td>7.4</td>
<td>7.6</td>
<td>6.4</td>
<td>7.8</td>
<td>8.0</td>
</tr>
<tr>
<td>MO helpful for communication</td>
<td>6.8</td>
<td>7.6</td>
<td>6.2</td>
<td>7.9</td>
<td>8.1</td>
</tr>
<tr>
<td>MO positive effect design process</td>
<td>7.0</td>
<td>7.4</td>
<td>4.7</td>
<td>7.7</td>
<td>7.7</td>
</tr>
<tr>
<td>MO positive effect final design</td>
<td>6.6</td>
<td>6.2</td>
<td>4.5</td>
<td>7.2</td>
<td>7.5</td>
</tr>
<tr>
<td>expect to use MO in daily practice</td>
<td>6.6</td>
<td>6.1</td>
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It shows clearly from the results of the questionnaires that the participants of the workshops thought the use of morphological overviews of value to the communication and the increase of relevant alternatives within the design process.
6. DISCUSSION AND CONCLUSION

We see morphological overviews as a valuable tool as well in the processes of the development of new design knowledge as in the analysis of this development. Morphological overviews can structure the design (activities) and the communication between design team members, forming the basis for reflection on the design results; both by the design team members themselves as in external discussion (with the client, but also for education and research purposes). This reflective element stimulates reflection-on-action between individual designers within team design process and can be seen as reflection-in-action on a design team level. Based on the integral design method and the C-K theory the morphological overviews are not merely used as a brainstorm tool but as a tool to structure the design process and stimulate the creation of new design knowledge. The evaluation of all the material of the observations is still in progress and this we will focus on the actual appearance of nODK, new object design knowledge.

Besides for developing and testing, the ‘learning by doing’ workshops were also meant to transfer this ‘ID-methodology’ to the daily practice of main building design disciplines. Maybe the best proof for the success of our approach is the fact that the workshops have become a part of the permanent professional education programme of the Royal Institute of Dutch Architects (BNA) since 2006.

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