Architect and structural engineer communicating in multi-disciplinary creativity.

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ABSTRACT: A collaboration approach is presented for the design negotiation of the architect and the structural engineer. This approach wants to instigate a design process where architectural shape and structure are designed simultaneously, and design decisions are made within the logics, objectives and culture of both disciplines together. Starting from the techniques of multi-disciplinary design optimization with quantifiable design parameters, a negotiation model is constructed for non-quantifiable design parameters. This model focuses on the communication through concepts during negotiation. This communication of the design proposition of the architectural shape and of the structure, has been further analyzed in this paper.

1 MULTI-DISCIPLINARY DESIGN

1.1 *Multi-disciplinary versus mono-disciplinary creativity*

When making an architectural design, many criteria (e.g. budget, function, expression, environment) have to be taken into account. Structural stability is one of these criteria. Since the shape of the building is directly related to the structure which holds it together, the structural system of the building is basically designed when the shape is designed. Therefore it is important for architect and structural engineer to work together early in the design process in order to design architectural shape and structure together.

The work of the structural engineer consists mainly of an incomputable creative part (e.g. designing the structural system) and of a computable scientific part (e.g. dimensioning a structural element). When designing the structural system, the engineer operates within the logics, objectives and culture of the engineering field. The same can be stated about the architect when designing the architectural shape. When the design step is taken considering the logics, objectives and culture of only one discipline, the author calls this mono-disciplinary creativity.

This type of creativity often occurs when the design process develops through a sequence of single solution propositions (e.g. a dimensioned structure) in answer to precise defined questions from the opposite field(e.g. to dimension the structure for an already designed shape). This type of sequential decision making process, follows a leader/follower protocol (Lewis & Mistree 1997). The collaboration between architect and engineer is then mainly a negotiation of the volumetric dimensions of the architectural shape and the structure.

The author's research wants to promote a design process where the design steps operate within the logics, objectives and culture of both fields, and architectural shape and structure are designed simultaneously and not in consecutive order: the design of the architectural shape is considering structural objectives and the design of the structure is considering architectural objectives. This design process involves a multi-disciplinary creativity, as the author has called it, and refers to Arup's search for an 'integral design' (Arup 1970).

1.2 *Multi-disciplinary design*

Multi-disciplinary design, as a design process which involves different disciplines, has been researched among others in the airspace industry (Lewis & Mistree 1997, Chen & Lewis 1999) and in the architecture, engineering and construction industry (Lottaz et al. 2000) with the purpose of optimising the design result. This has been made possible through the use of numerical design parameters, mathematical relationships and numerical evaluation of the design result. One of the techniques to come to a multi-disciplinary design optimisation, is through the use of a range of design solutions instead of a single design solution during negotiation between different disciplines. This range of solutions is obtained by keeping certain design parameters undecided, and mathematically defining objectives that holds a design optimisation within a specific discipline. When all disciplines involved propose such a range of solutions, software is then able to optimise the undecided design parameters to find an optimised design result. The collaboration process were each different profession proposes a single design solution, risks to eliminate this optimised design result because some design parameters are chosen without the necessary expertise of the other professions involved.

When architect and structural engineer design architectural shape and structure together, they are not dealing with pure numerical problems, and the overall evaluations of the design result is not quantifiable. So the above mentioned numerical method of optimization cannot be applied.

But even though the design optimisation cannot be quantified for the overall architectural design, the architect still decides which design proposal meets best the different objectives (i.e. a non-quantifiable optimisation). This collaboration concept of proposing a range of design solutions instead of the single design solution for negotiation is therefore still applicable. Keeping this range of design solutions large during the different negotiations enables the different professions to provide additional discipline specific information without narrowing down the design possibilities too early in the process. This method of collaboration can be applied to all professions involved in designing architecture. The scope of the author's research is limited to the profession of the architect and the structural engineer.

Proposing a range of design solutions requires that several design decisions still have to be taken. Therefore the collaboration between the two professions needs to be early in the design process: architectural shape and structure still need to be designed.

A range of architectural and structural design solutions can be obtained through the use of conceptual propositions instead of the dimensioned and materialized single solution. A structural or architectural concept mainly determines the objectives of the design proposition without being too detailed or specific.

1.3 *Communication during design collaboration*

The understanding of the structural or architectural concept as a range of design solutions, is embedded in the specific terminology, logic and culture of the according discipline. For the architect to understand the structural concept, he must possess sufficient structural knowledge, and vice versa for the structural engineer. According to Fauconnier, this communication between architect and engineer will only be successful if they possess the same –internal- 'system of thoughts' (author's translation of 'Gedachtensysteem') and understand the same -external- 'system of symbols' (author's translation of 'Systeem van betekening') on this mutual ground of structural and architectural knowledge (Fauconnier 1986).

During this collaboration different kind of representations are used with different purposes: consultation drawings to elicit a response, diagrams –very reductive and simplifying properties- to reflect, and proposition drawings to put down in order to stand back and look at it (Lawson 2004). These drawings are often accompanied with verbal explanations.

The heart of the design process lays in these proposition drawings which are related to Dark's idea of 'conjecture'(Dark 1984): proposing one particular solution concept. This conjecture is then evaluated, and thereby the design problem further analysed in order to generate a better design proposal. For architect and engineer to operate both at the core of designing structure and architecture, it is important to understand each other's propositions or conjectures which are embedded in the different disciplines.

2 CREATIVE COLLABORATION OF ARCHITECT AND STRUCTURAL ENGINEER

2.1 *Applied methods of research*

The author has a practice as structural engineer and as teacher to architecture students for more than 14 years. Based on this personal experience and literature study, research actions are set up within these practices through participatory action research. Propositions to improve the conditions for multi-disciplinary creativity, are tested in the author's practices and evaluated for further adjustment after critical reflection. In this research the author takes the role of structural engineer during the collaboration with architects and architecture students.

The findings are presented to peers for commenting through formal and informal interviews with practicing architects and structural engineers, through paper presentations at conferences and through academic discourse.

The type of building projects this research is conducted in, is strongly focused on this 'integral design' (Arup 1970), where architecture and structure are in balance. These projects are often of a limited size (i.e. a building budget up to two million Euros) with a short span of collaboration.

The following describes a collaboration approach to instigate multi-disciplinary creativity, based on the findings of the author's research.

2.2 *Conditions for multi-disciplinary creativity*

Multi-disciplinary design optimisation intends to avoid unnecessary conflicts during design negotiation between the different professions, through the use of a range of design solutions instead of the single design solution. During negotiation between architect and structural engineers these conflicts are often a result of conflicting architectural and structural volumes (i.e. the volume of the three dimensional (3D) virtual model of the design solution), and of conflicting architectural and structural objectives.

Through the use of conceptual design propositions as a range of design solutions, these conflicts can be countered. This requires of the collaborators a sufficient understanding of the opposite proposition on the level of its volume and objectives.

These objectives are to be understood within the terminology, culture and logic of the discipline. They indicate how the representation of the 3D virtual model of the design proposition is to be interpreted: the conceptual design proposition is a range of volumes of single design solutions that are true to these objectives.

In order to instigate multi-disciplinary creativity, the objectives of the opposite field should be incorporated in the design process of the own field. This will not only lead to a design proposition that fits within these opposite objectives and thus avoiding negotiation conflicts, but can also provide inspiration to the own design process and open unexpected possibilities to the opposite design process (e.g. villa Bordeaux of OMA in collaboration with Balmond, where the

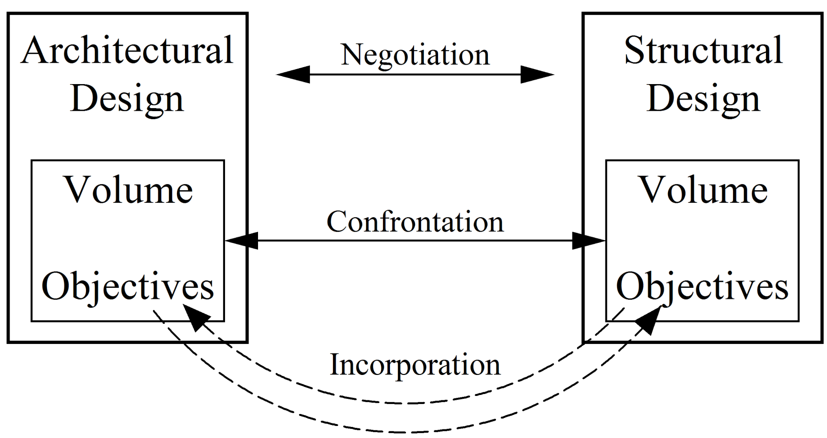


Figure 1. Diagram of architectural and structural design negotiation.

architectural objective of ‘flying’ instigated a creative and uncommon approach to the structural design process (Balmond 2002)). All this requires of the collaborators to possess sufficient knowledge of the opposite field on the level of terminology, logic and culture.

In this communication it is important to present the design proposition through a filter: unnecessary information is best avoided to keep the focus on the essence. What should be conveyed of the design proposition are those characteristics that matter to the design process in the opposite discipline, and the essence of the proposition within the own discipline. It also requires a communication appropriate to the level of refinement in the design process: the more the process evolves the more detailed the representations will become.

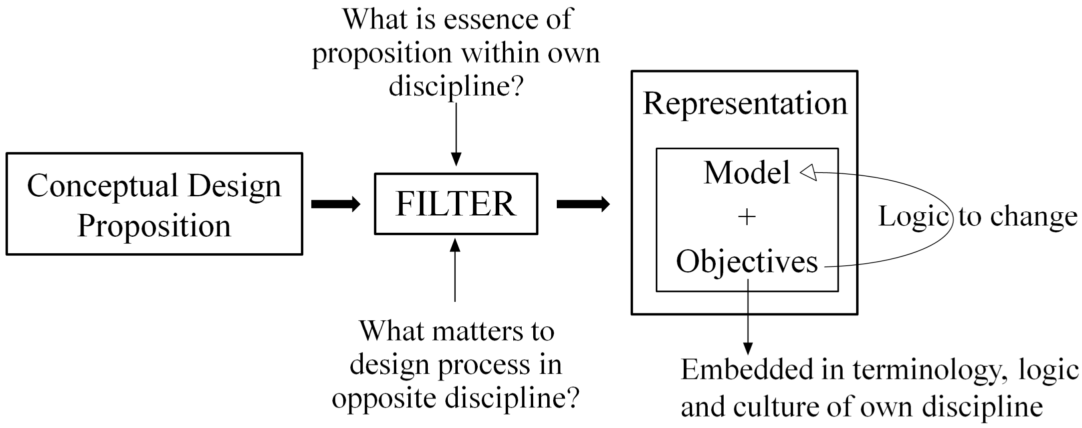


Figure 2. Diagram of the representation of the conceptual design proposition.

This kind of collaboration asks for interpersonal contact with quick response on questions posed, and direct feedback of the communication (Luyten 2009). This implies a swift way of representing the proposed design solutions during these multi-disciplinary design sessions.

This collaboration should start early in the design process when shape and structure are not designed yet (see above), and with open questions and answers, letting creativity take place in the field of the expert-collaborator (e.g. structural concept being mainly designed by the engineer and not by the architect).

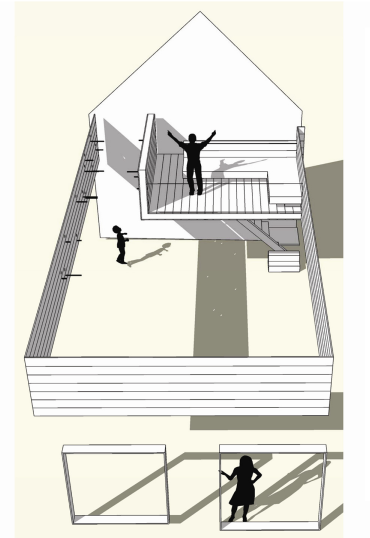
Summarizing these settings for multi-disciplinary creativity:

- Conceptual propositions (as a range of design solutions)
- Use of filter in communication
- Collaboration early in the design process
- Sufficient knowledge of the opposite discipline
- Appropriate level of refinement in communication
- Open questions and answers
- Interpersonal contact

2.3 *The representation of the architectural design proposition*

Early in the design process the architectural design is taking form, but still needs further development. This development is guided by the chosen architectural concept of the design. This concept is at the base of the architect’s design proposition and represents a range of (possible) single design solutions. A chosen concept is not fixed in time and can change during the design process.

By presenting a visual 3D-model (e.g. through ground plans and cross-sections drawings) and a verbal explanation of the architectural concept, this range of design solutions is conveyed. Although this 3D-model might give the impression of a single design solution of the building’s



Architectural objectives

- Sun terrace: attainable by the sunlight
- Lodge: theatrical element, with a view upon
- Almost floating: floating plane, no columns
- Drawer: volume coming out of the wall
- Independent volume: disconnected from other elements
- Wooden materials: wooden surfaces
- Transparent banister: safe and see-through
- Build without crane: everything man carried

Figure 3. Example of architectural design proposition and objectives. (© K. Vanmerhaeghe)

volume, the proposition embraces more possible volumes that are true to the architectural concept than the one visualized.

The overall architectural concept can often be divided in a hierarchy of sub-concepts that contain a clear single objective within the architectural discipline. These objectives can have a parametrical nature (e.g. a required percentage of light penetration through a wall) to a pure aesthetical one (e.g. a certain expression of the facade). They can only be understood within the terminology, logic and culture of the architectural discipline. The sum of these objectives determine the overall architectural concept and the way in which the visualized 3D-model, as a volume, can be altered to stay true to this overall concept.

When designing structure is about corresponding the structural volume with the architectural volume, it is important for the engineer to understand the range of architectural volumes that is presented. Thus in order to alter the visualized volume, the engineer has to understand sufficiently the terminology, logic and culture of the architectural discipline in which these objectives operate.

The confrontation of the architectural and the structural design is not only on the level of volumes, but also directly on the level of objectives. Although these objectives are not fixed in time and can change during the design process, sometimes architectural objectives stand in the way of structural objectives, and vice versa. A method to overcome these conflicts of objectives, is by implementing the objectives of the other discipline in the own design process. When successful, the developed design propositions are true to the objectives of the opposite collaborator.

Because these external objectives are often uncommon objectives to the own design field, they can provide inspiration and a different approach to the design creation (e.g. villa Bordeaux of OMA, see higher (Balmond 2002)).

In this communication it is important that the architect filters his design proposition in function of what he understands as being the architectural essence of his design, and what is of matter to the structural design process. Redundant information risks of shifting focus away from the essence of the collaborative design process.

2.4 *The representation of the structural design proposition*

As with the architectural proposition, the structural proposition –as an answer to the architectural design problem- represents early in the design process, a range of structural design solutions. This proposition can be presented through a visual representation of a 3D-model and a verbal explanation of the structural concept. In essence this 3D-model visualize the structural system: it consist of the different elements with their structural function, and of the connections between these elements. The configuration and the structural function of the structural elements are the objectives of the structural design proposition. These objectives are to be understood within the discipline of structural engineering.

The structural functions of the elements are related to the imposed loads, and represent the course of the load paths through the element ('load path' as concept described by Millais (Millais 1997)). Revealing these load paths in the structural system provides a common language for architect and engineer during the design of architectural shape and structure (K. Olsson et al. 2008).

The functions of a structural element can for example consist of transmitting a load along its axis (e.g. a bearing wall) or divide the load by means of bending moments (e.g. a beam or a floor plate), or relocate the load to another working line (e.g. wind bracing).

Most structural elements have several functions, and it is up to the engineer to filter them and only present the fundamental functions to the architect. The representation of the structural proposition should visualise these fundamental functions together with the configuration of the structural elements and their connections (i.e. hinge, bending stiff, and so on). This represents the logic of the structural proposition, and thus its objectives. This also provides the possibility to change the configuration of the structural model within these objectives.

Each structural element with its structural function can be refined according to clear structural rules to come to the final building material and form. This is a question of organizing structural matter to do the required job: kneading the structural form. For example, a vertical plane with the function of dividing a vertical load onto two supports (i.e. the principle of a beam), can be refined into a perforated beam, a truss, a Vierendeel-girder or a cable structure. And thus this structural element (vertical plane) with its fundamental structural function (dividing load), represents in itself a range of structural design solutions.

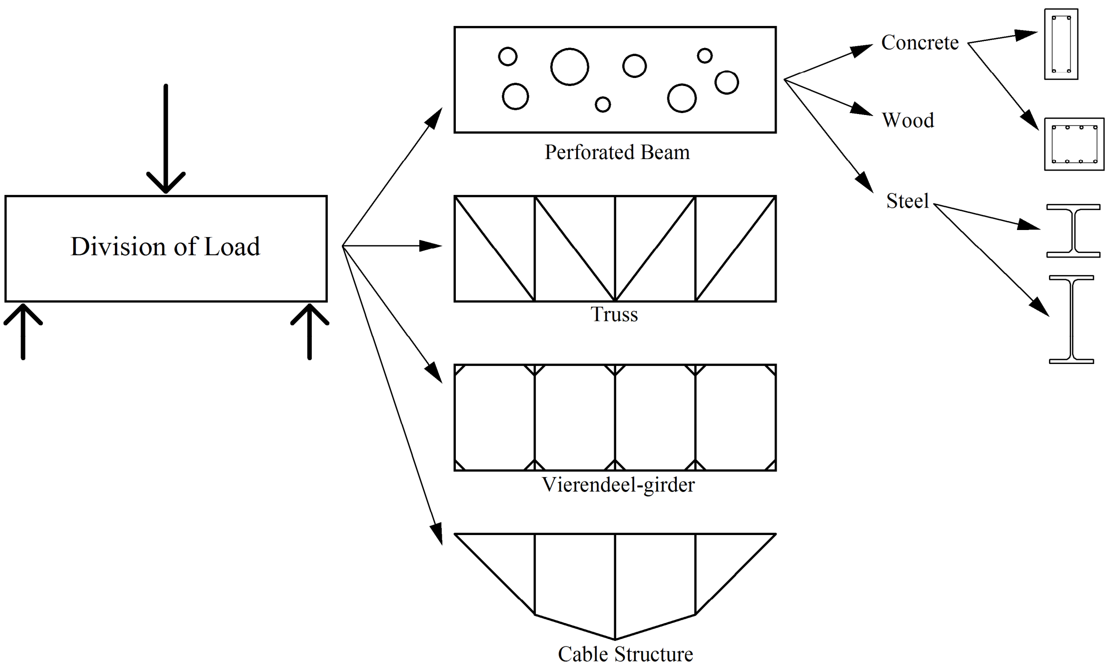


Figure 4. Example of a structural design refinement.

There is a level of refinement in these structural elements, going from a solid over a surface to a line, by which the actual materialised form can be represented. In this further development of organizing structural matter, one can start from solids to come to a configuration of surfaces and end with only lines, as the range of structural design solutions diminishes.

In this communication with the architect this representation intends to be visual and direct in conveying the structural objectives: 'visual' in order to relate to the natural communication medium of the architect, and ‘direct’ by presenting only one model instead of a multitude of diagrams (e.g. of bending moment, normal force, and so on).

Instead of using symbols to express the structural function of the elements, it is also possible to use a structurally logic form for an element and its function, by optimally dimensioning the element for a virtual isotropic material (e.g. a straight line element transmitting a tension load = a cylinder with a small diameter). This materialisation of structure operates in the realm of volumes and shapes, which is the architect’s playground. Still the architect needs sufficient understanding of the engineering discipline in order to comprehend the presented objectives in order to incorporate them in his own design process.

3 CONCLUSION

A collaboration approach has been presented to instigate a design process where structure and architectural shape are designed simultaneously, and design decisions are made within the logics, objectives and culture of both fields together. In this approach a range of design solutions are used for negotiation between architect and engineer, through a representation of the conceptual design proposition. This conceptual understanding of the proposition is embedded in the specific terminology, logic and culture of the involved discipline. In order to obtain a successful communication between architect and engineer on this conceptual level, both actors need to possess sufficient knowledge on the opposite field.

This communication of the design proposition needs to be filtered by focusing on the essence of the design proposal in function of the design process of the opposite collaborator.

The negotiation between architect and engineer involves a confrontation of the volumes and objectives of the architectural and structural design proposition.

A multi-disciplinary design process where design steps are taken considering both disciplines, can be obtained by incorporating the design objectives of the opposite field in the own design process. Implementing these external objectives will reduce the risk of design conflicts during negotiations and can inspire the own design process.

In this approach the architectural representation consist of a visual representation of a 3D-model and a verbal explanation of the architectural concept. This concept can be divided in different architectural design objectives of the design proposition. These objectives determine how the properties of the presented 3D-model can be altered to stay true to the architectural design proposition.

The structural representation also consists of a 3D-model, visualizing the structural system, and a verbal explanation. The structural system consists of the different structural elements, their function, and their interconnections. The structural objectives of the design proposition are expressed by the configuration of the structural elements and their functions, revealing the load paths of the imposed loads. Only the most fundamental functions are to be presented to the architect.

Following structural logic, the configurations of the structural elements can be changed within the presented objectives and stay consistent with the design proposition. Within the same structural logic, the structural element in combination with its function, can be further refined: organizing the structural matter.

The representation of the structural proposition should be visual and direct. This can be obtained through a 3D-model of the structural system and through the function of its elements expressed by a symbol and/or an appropriate materialization of its shape. Further research is to be done on developing this language for a structural representation, that is easy and fast in use during design negotiation.

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