11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
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HYBRID DESIGN METHODS FOR COMPLEX SYSTEMS IN ARCHITECTURE & STRUCTURAL ENGINEERING

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Key Words: *Architecture, Structural Engineering, Computing, Scripting, Programming, Planning and Consulting, Finite Element Analysis (FEA), Computer Aided Design (CAD), Complex Systems, Hybrid Systems, Simulation.*

Abstract. This paper explores hybrid design methods for complex structural systems involving both customizable computing methods (e.g. programming, scripting) and established computer applications, e.g. Computer Aided Design (CAD) and Finite Element Analysis (FEA). While working with complex structures - and the underlying data models - structural engineers have gained experience in performing precise predications. But CAD and FEA - based on one static data model – early reaches a critical point where either model precision falls bellow or the model size exceeds the limits.

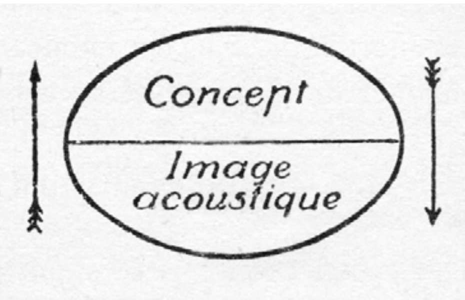
This paper aims at indicating the potential of hybrid design methods for complex structures and their evolution throughout the whole design process. If architects and structural engineers were able to define one consistent information model as some kind of common language, their comprehensive communication systems could sustain the whole design process. Architects and structural engineers shall focus on the enormous potential of information modeling and hybrid concepts of dynamization in order to encourage a process-oriented evolution of complex data discretizing layout, analysis, construction and detailing.

1 COMPLEX SYSTEMS – A STRUCTURAL APPROACH

The word complex means "consisiting of many different and connected parts" while being "not easy to analyze or understand" [1]. Computational mechanics deals managed objects based on discrete and mostly static data models. These data models usually represent a complex system over the whole design process including the layout, computational analyses as well as construction and detailing processes. When performing mechanical analysis with complex systems the engineers usually tend towards cutting the system. The simplification of systems to smaller systems indicates a way leading towards mechanical abstraction and hence perceivable and predictable phenomenona. Structuralism indicates an alternative solution methodology. Structuralism implies layering and stratification i.e. the creation of layered data models - representing the concept or image – in an arranged and classified manner.

The conception of structure turned up in biology of 17th century and was propagated in medicine, literature, philosophy and especially in linguistics. The idea of “structure” has often been associated with the idea of “system”. But an analysis of both ideas against the backdrop of “function” yields an opposition. A system can be functional, but merely structure cannot. The system consists of mechanisms and components e.g. constructions. An identical form of the system or its components could offer totally different functions. Form is bound to materiality and therefore part of the signified. Structuralism determines structure to be the signifier of a system.

Ferdinand de Saussure describes the linguistic distinction between the signifier (signifiant) and the signified (signifié). "I propose to retain the word sign [signe] to designate the whole and to replace concept and image acoustique respectively by signified [signifé] and signifier [significant]; the last two terms have the advantage of indicating the opposition that separates them from each other and from the whole of which they are parts" (Fig. 1) [2]. Although Ferdinand de Saussure makes rare use of the word structure, his linguistic theory laid the foundations of structuralism. De Saussure defines language as a system consisting of members. These members are at no circumstances defined per se, but derive in eminence and value from the other members.



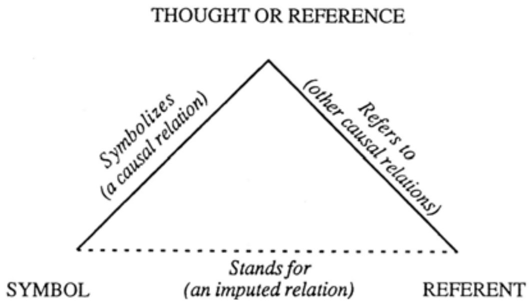


Figure 1: Opposition of concept and acoustic image designating one language term [2] - left side
The triangle of reference (semiotic triangle)pursuant to Ogden and Richards - right side

The triangle of reference (semiotic triangle) is a model explaining how a symbol (signifier) is linked with its referent (signified). While sometimes known as the Ogden/Richards triangle (Fig. 1) the underlying idea dates back to Bernard Bolzano and its basic concept can even be found in the suppositions of Parmenides (540 - 470 BC). The triangle of reference defines the basic concept of communication where words are the symbols placed on an imaginary layer (signifier) whereas objects are the referents that can only be found on the actual layer of real life (signified). The dualism digital/real – on which the specialist term computational (=digital) mechanics (=real) also refers – displays the same concept just as all the other disciplines of applied information technologies.

2 INFORMATION MODELING

In information technologies the main purpose of an information model (IM) is to model managed objects at a conceptual level. The terms "conceptual models", which is often used in the literature, relate to their structural function as a *signifier* (signifiant). An important characteristic of IMs is that they can (and generally should) specify relationships between objects [3]. Since IMs after the definition of Pras and Schoenwalder are protocol neutral, they can be implemented and mapped into manifold data models in the course of a process chain. IMs describe the managed environment and define the functionality of detailed models (DMs), which are concrete models for implementation. Both IMs and DMs are static models.

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              IM                --> conceptual/abstract model
               |                    for designers and operators
    +----------+---------+
    |          |         |
    DM         DM        DM     --> concrete/detailed model
                                    for implementors
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Figure 2: The relationship between IM and DMs [3]

In the last decade, architects and structural engineers have started to focus on building information modeling (BIM) that has been developed since the 1970s. BIM offers a structure of DMs linked by an IM. BIM provides the easiest access to structuralism for architects and structural engineers. Many appreciate the power of BIM – a smart and effective technology – when working on complex projects, although the IM is neither fully customizable nor dynamic without restriction.

3 THE DYNAMICS OF HYBRID DESIGN METHODS

Hybrid methods cover on one side discrete static models and on the other the continuous flow of dynamic information interchange. Any dynamic information interchange implies a communication system. Claude Elwood Shannon, a mathematician, discovered the formula defining the entropy of data transfer and postulated *A Mathematical Theory of Communication* [4].

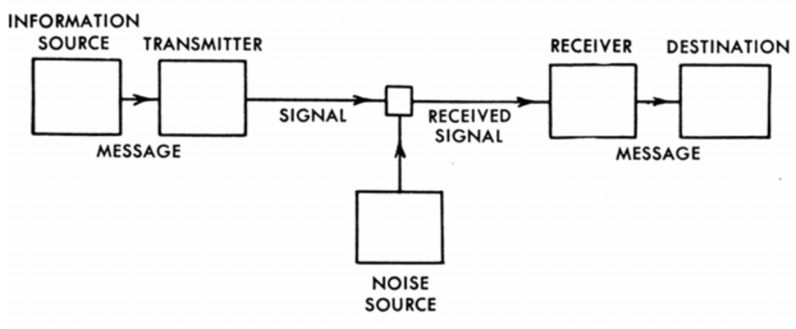

Figure 3: Schematic diagram of a general communication system [4]

Shannon's theory of communication defines a basic model for data transfer showing the communication process based on signals between a source and a destination (Fig. 3). "Noise" source characterizes anything associated with the transferred data and appears on three succeeding levels:

- Technical level: signal transmission, system parameters, etc.
- Semantic level: representation, language selection, etc.
- Effectiveness level: effect at destination, alternatives, etc

Any "noise" source operating on the semantic or the effectiveness level manipulates information while being transferred. Manipulated information exerts an influence on the data model controlling the complex system. A third player *performing* small interventions on a "noise" layer would exert an advantageous influence if he was *competent* to favorably organize the layer . The dichotomy *competence* and *performance* has been introduced by Noam Chomsky continuing the distinction between *signifier* (signifiant) and *signified* (signifié). In *Aspects of the Theory of Syntax* Noam Chomsky stresses the need for *Generative Grammar* where the knowledge of a language is based on the competence of dealing with a finite number of elements. This competence is not observable since it is based on experience, skills or the presence of any kind of knowledge.

Noam Chomsky explains:

> *Perhaps the issue can be clarified by an analogy to a part of chemical theory concerned with the structurally possible compounds. This theory might be said to generate all physically possible compounds just as a grammar generates all grammatically 'possible' utterances. It would serve as a theoretical basis for techniques of qualitative analysis and synthesis of specific compounds, just as one might rely on a grammar in the investigation of such special problems as analysis and synthesis of particular utterances." [5]*

Generative design methods represent a promising strategy beyond the system. Generative design methods are based on a smaller number of structurally possible compounds from which they can create all physically possible compounds for the complex system. Design competence can be based either on digital perfection or on human excellence when generative strategies like mapping, collectivity and evolution are effective design methods [6].

Figure 4: The Design process in the dualism of digital perfection and human excellence

Computer algorithms can perform evolution with information coming from inter process communication (IPC) with professional computer applications working on DMs [7]. Human workgroups can perform evolution on common platforms with data interfaces. Any effective communication – IPC or human communication – is subject to information models (IMs) that specify the relationships considering geometrical orders and design configurations. Designers can also modify DMs directly or indirectly via computer code in order to generate variation [8]. Effective control of complex structural systems should be attributed to the comprehensive deployment of communication systems when working on different DMs.

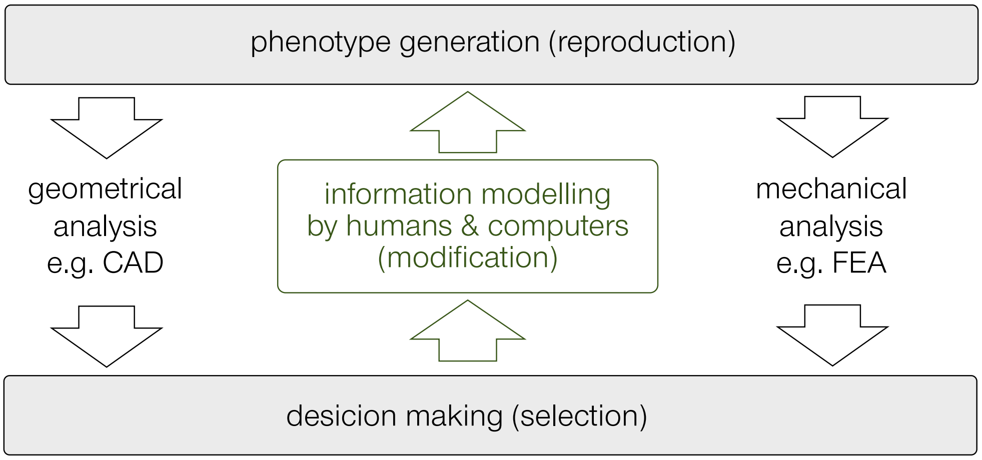

Figure 5: Design progress based on evolution performed by humans and computers

4 HYBRID DESIGN – WORKING ON A COMMON PLATFORM

LAVA, the architects, have developed an ambitious canopy for a solar supercharger. The solar supercharger is a station where batteries for electric vehicles can be fully charged in less than one hour. The canopy is specified by a NURBS surface, which is the design surface for the aluminium construction produced with CNC laser cutting.

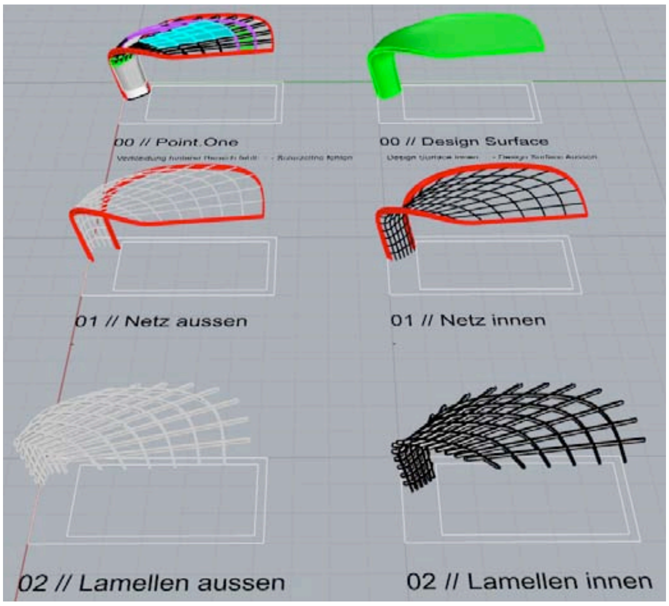

Figure 6: Early detailed models from the architect (©LAVA)

The double curved surface has been built with plane aluminium sheets. The sheets are based on individual prefabricated patterns with holes, flaps and notches. The result originates when interlocking the sheets. Since the anodized aluminium sheets with a thickness of 3 mm (11 ga) have neither a significant load capacity nor a sufficient stability, we had to evolve the form including the dimensions of plate width and node spacings.

At first, an information model defined the required detailed models for geometrical and mechanical analysis. NURBS surfaces represent the geometry of the aluminium sheets. Lines define the structural elements for mechanical analysis. Different layouts for single and double layered areas have been coordinated.

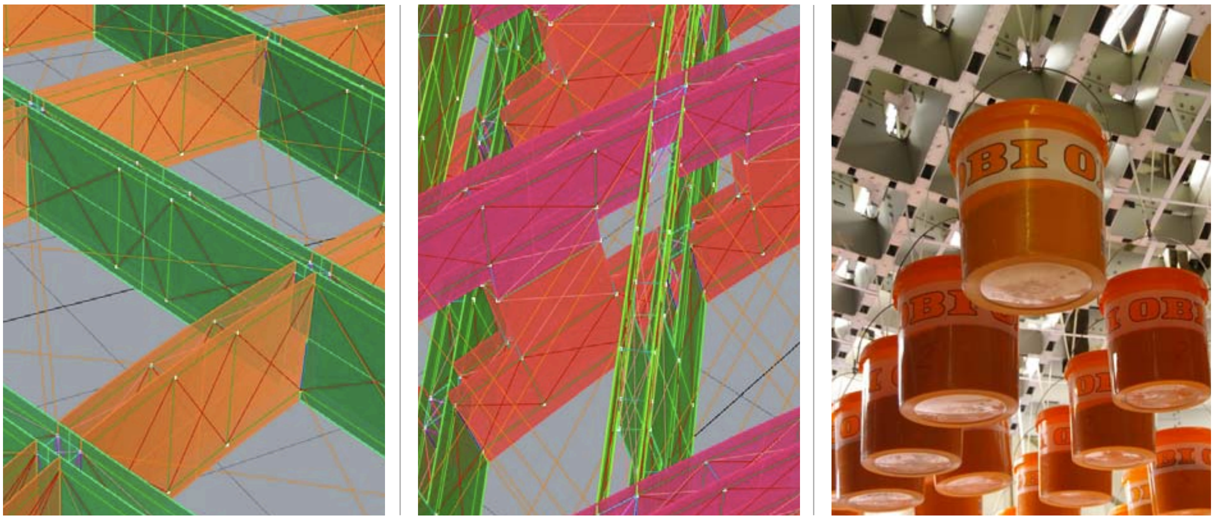

Figure 7: detailed models for mechanical analysis - real stress test with filled buckets

The information model (IM) has been the common platform for the shaping of the canopy. It specifies the relationship of more than 22,000 structural elements with respect to the aluminium sheets. Besides, the information model also served as an interface providing the required data for the other detailed models (DMs) like buckling analysis or node detailing. The shaping of the canopy has been a design process including 12 phases of reshaping with geometrical and mechanical analyzes.

The final result has been built and verified by a real stress test with filled buckets representing the snow load.

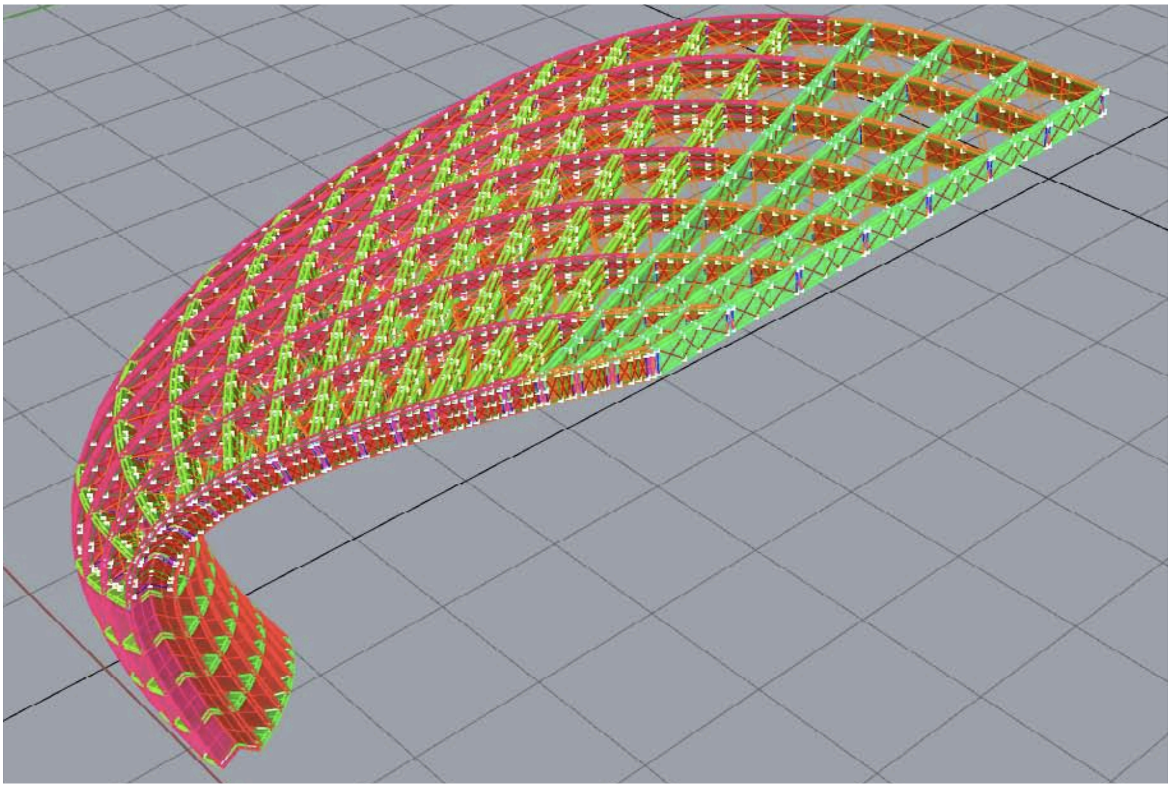

Figure 8: Information model for geometrical and mechanical analysis (©designtoproduction, consuplan.de)

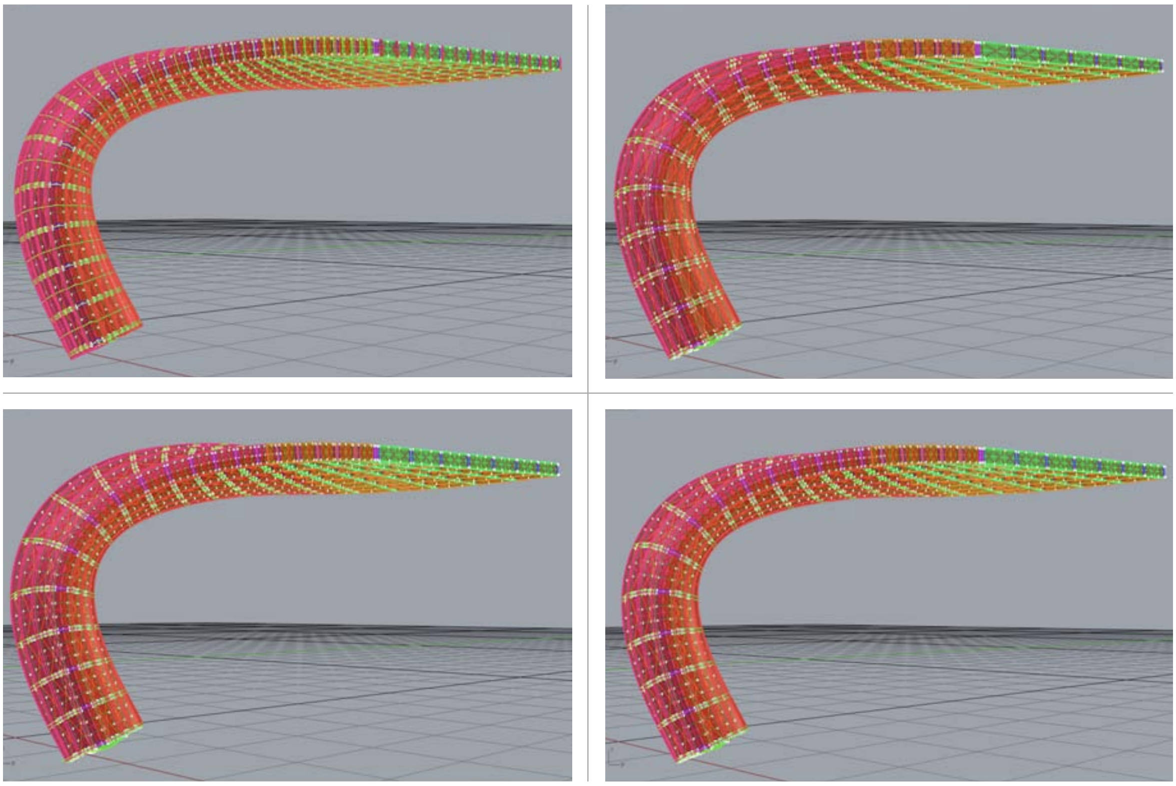

Figure 9: Four different phenotypes have been modelled in a hybrid design process

Figure 10: Point_One – the solar supercharger for BMW (hand-warped plane 3 mm aluminium sheets)

12 CONCLUSIONS

Hybrid design methods are an effective approach to the design of complex systems. Hybrid design is performed by human networks, by computers (artificial neural networks, ANNs) or in turns. Information models (IMs) are important to predetermine the scope of the communication system connecting detailed models (DMs). Detailed models (DMs) define the structurally possible compounds. Hybrid methods combine static and dynamic strategies. Information models (IMs) help accelerate dynamics.

Future architects and structural engineers will have to focus on information modeling and hybrid methods. Accelerated dynamics encourage a target-oriented evolution of complex data models. Hybrid design methods can cover the whole design process including layout, mechanical analysis, construction and detailing.

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