International Journal of Design Sciences & Technology

Volume 19 Number 1

ISSN 1630 - 7267

Irlwek M and MengesA. (2012). The Extension of Rittel´s Methodolgy in Contemporary Parametric Design, International Journal of Design Sciences and Technology, 19:1, 1-25

Editor-in-Chief:
Reza Beheshti
Khaldoun Zreik

ISSN 1630 - 7267

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The extension of Rittel´s methodology in contemporary parametric design

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The problems of creating and reducing variances in a relevant way are inherent to parametric design processes. The question occurs whether it is possible to develop methods which aid designers in generating relevant decisions in systems and subsystems, in order to produce meaningful variations in the solution space. Based on Rittel´s methodology dealing with wicked problems during the cooperation of different disciplines, we have looked at the concept of creating variations and reducing them for the case of parametric design, which allows high flexibility and strategic exploration but may lack filtering mechanisms. To the best of our knowledge, this has not been done before.

Keywords: wicked problems, design methods, computational design, parametric-algorithmic design

1 Motivations for new parametric design methods

Design is change. Parametric modelling represents change. Parametric modelling (also known as constraint modelling) introduces a fundamental change: “marks”, that are parts of design, relate and change together in a co-ordinated way. No longer must designers simply add and erase. “They now add, erase, relate and repair".[1]

The complexity of design processes can grow extremely. Therefore, a systematic approach is needed when building up the solution space. The more disciplines of different experts and knowledge domains are involved in a process, the more arguments and positions are exchanged that are forming the process.

Design begins when problems can be formulated. However, to be able to formulate a question to a given problem the solution is also already being thought of.[2] More specifically, to formulate a problem coherently, it is essential to collect different positions from all design participants, although they posses a different level of information and knowledge. Information emerges furthermore as the process evolves, which changes the formulation and definition of the previously defined problems. Therefore, the design process is an open, dynamic system, which is hard to work with. We can never be sure if the produced variations are originating in relevant information and efficient knowledge. Therefore, variations are not necessarily to be seen as solutions.

Wicked problems create even worse scenarios: They are interpretable and generate always more than one solution, one can never be sure if the problems themselves or just symptoms of these are being solved.[3] In parametric design processes, it would be outstanding if we would be able to create mechanisms, which allow us to choose relevant parameters and variables in order to come to relevant

1 Woodbury R. (2010). Elements of Parametric Design, Routledge, London
2 Rittel H. (1972a). On the planning Crisis. Systems Analysis of the „First and Second Generations”, IGP, Universität Stuttgart, in Bedrifts Oekonomen 8
3 ibid

4 Rittel H. & **Noble D.** (1988). Issue Based Information Systems, A-88-2, IGP, Bibliothek Institut für Grundlagen der Planung, Universität Stuttgart
5 Rittel, H. & **Webber M.** (1977). Dilemmas in a General Theory of Planning, S-77, IGP, Bibliothek Institut für Grundlagen der Planung, Universität Stuttgart
6 Rittel H. (1972a). ibid
7 ibid
8 ibid

variations. Each variation would then contain meaningful criteria that are already a part of the solution space. Furthermore, this requires generic mechanisms that restrict such variation in order to make the design process converge.

- We adopt Horst Rittel´s methods on collecting variables and parameters of the parametric design (context variable, performance variable and object variable) with an IBIS (Issue Based Information System), restricting emerging variations through filter systems (Section 2)[4]
- Criteria define filter systems. They are constructed by an overlap of arguments. We will elaborate in Section 3 show how students from the University of Stuttgart developed different design systems out of a common design agenda.
- The computational process is often seen as a tool. We argue that it should rather become an equal partner, which extends argumentative design processes by giving generative inputs (Section 4).
- Argumentation serves finding of a common mental denominator. This common denominator is a basis for the formation of a constraint system, which can be thought of as extension of the filtering mechanisms proposed by Rittel. In Section 5 we give further details on implementing these constraint systems with special emphasis on linking parametric modelling components such as lofting, extrusion, Boolean operations, etc. In Section 6 additionally the impact of constraint systems on wicked problems is described.

As a result of our efforts (Section 7), we envision that parametric design is seen with reference to already existing design-methodologies, which serve a basis to a rigorous understanding of decisions and extended methodologies made during a project.

2 State of the art

2.1 System sciences

Based on Horst Rittel´s research each question of a design process can be declared as a question within an information process.[5] Design processes can be informed and conditioned by self-stabilising learning processes. Rittel distinguished between "tame problems", which are declared as problems of the first generation. These problems are solvable without further information.[6] Questions can be answered with "yes" or "no". The criteria are clear and allow just one solution of the problem. Unsolvable assignments are in mathematical sense functions, which deliver more than one solution. These solutions have more facets. Solutions, which contain more facets, are interpretable. These problems are characterised as "wicked problems" and are problems of the second generation.[7] Design processes inherit many problems so called problem-bundles of different characters. During a process, problems can be solved partially, become abandoned or emerge according to a set timeframe. Problems are linked and cannot be seen independently. The particular solution of one problem has effects on problems of other disciplines. A desirable solution is due to this complexity not predictable. The question occurs if the problem is completely solved or just partially, because of unpredictable links to other problems. Rittel speaks about symptoms of problems.[8]

"Every wicked problem can be considered as a symptom of another problem and you are never sure if you are attacking the problem on the richest level, for curing symptoms can make the real disease worse. Wicked problems have no immediate nor an ultimate test to the problem. Each action what was carried out in response to a problem can have consequences over time. There is no ultimate test because there can always be additional consequences which might be disastrous and which result from what runs out be a very bad plan”.[9]

Walter Schönwandt developed the third planning generation, based on Rittel’s research.[10] This generation incorporates events and environmental models as specific scenarios to the design process and determine the link to real problem definition processes. The exchange of arguments between process related persons brings the design process in a dynamic state. Christopher Alexander wrote in the “Notes on the synthesis of form” about “tree structures”, which have a flat hierarchy.[11] Comparable to Rittel´s systematic solution finding process, Alexander researched in the field of mathematical form generic. The extensions of this theorem led him to think about linking the systems and subsystems together. Not each subsystem has to be connected to another subsystem. There are families of systems. The aim is to find through decentralised, network based systems a way to increase information flow. The exchange of arguments based on information on different levels of systems and subsystems allows a complex and multileveled transfer of knowledge. Rittel´s IBIS (Issue Based Information System) works on data flow and the generic of knowledge transfer.[12] Team dynamic processes can be organised hierarchically or network-based (Figures 1 and 2).

Knowledge is important to define meanings and aims, which are essential to clarify form specific issues. Different meanings and positions are for multilayered and rich developments of a dynamic design process very important. "A person’s response to an issue is called a position”.[13] Criteria are results of comprehensive informational exchange and describe an overlap of existing positions. Generating and constricting of relevant variations are parts of increasingly complex systems and different states of systematic behaviour shown in Figures 3 to 6.

9 ibid

10 Schönwandt, W. (2008). Planning in crisis? Theoretical orientations for architecture and planning, Ashgate Publishing Company, Hampshire, UK

11 Alexander C. (1971). Notes on the synthesis of form, Cambridge, Harvard University, Press London

12 Rittel H. & **Noble D.** (1988). ibid

13 ibid

14 Rittel H. (1969). Zukunftsorientierte Raumordnung. Systems 69. Internationales Symposium über Zukunfts-fragen DVA, Bibliothek IGP Planung, Universität Stuttgart

15 Reuter W. & **Werner H.** (1983). Thesen und Empfehlungen zur Anwen-dung von Argumentativen Informationssystemen. Harald Werner, Gesellschaft für Information und Dokumentation bmH (GID), Sektion für Syste-mentwicklung (SfS). A 83-1 IGP Institut für Grundlagen der Planung, Universität Stuttgart

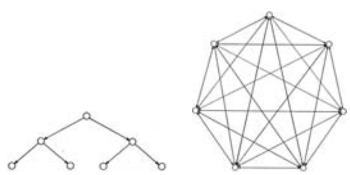

Figure 1 Horst Rittel Structures of team dynamic workflow - hierarchy or team?[14]

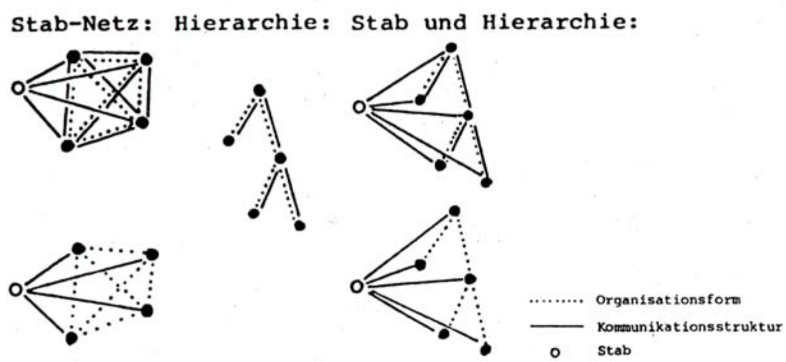

Figure 2 Wolf Reuter Forms of organisation, communication structures[15]

16 Rittel H. (1972a). ibid
17 ibid
18 Irlwek, M. (2010). PHD Research Project, Extensions of Rittel´s Methodology

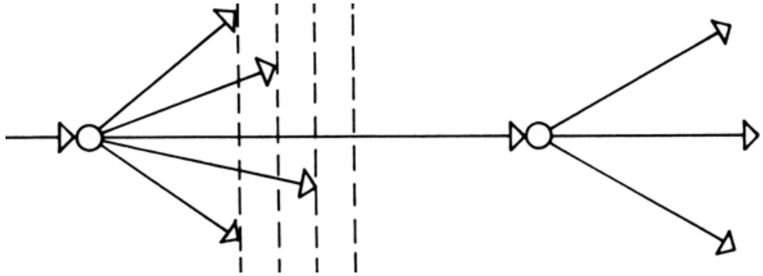

Figure 3 Horst Rittel Generating and restricting of variables[16]

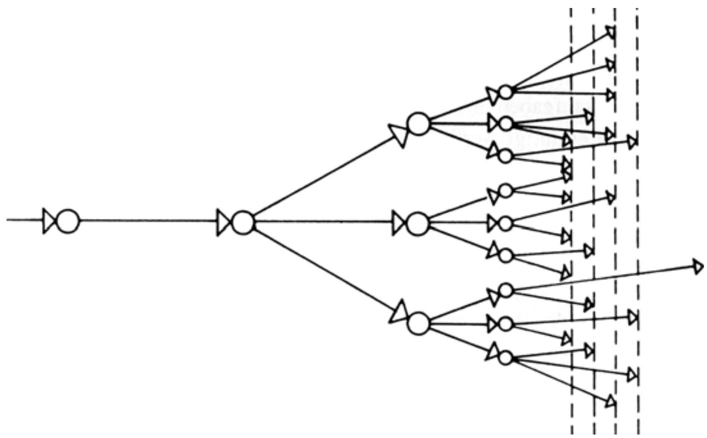

Figure 4 Horst Rittel Filter systems[17]

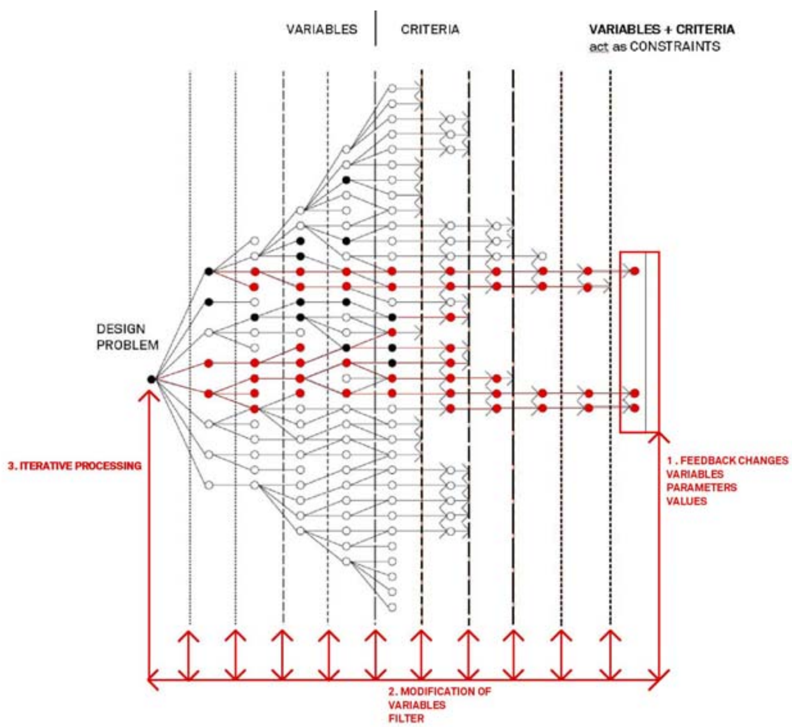

Figure 5 Irlwek PhD Research Project. Extension of Rittel´s Methodology[18]

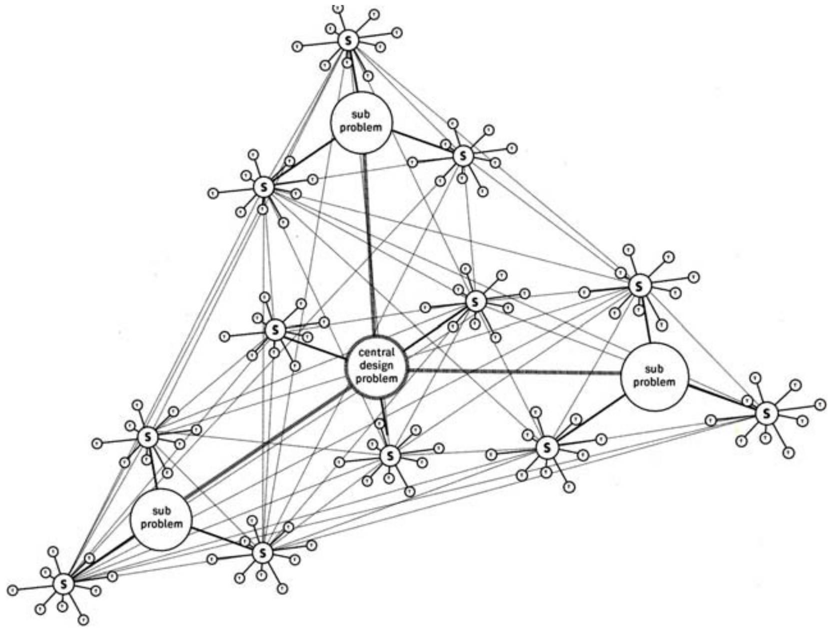

Figure 6 Wicked problems[19]

Multileveled and changeable positions have an effect on the lines of argumentation during a design process. Thus the process is subjected to a supervision of permanent differentiation. The diagram of reducing variables to get only one solution functions for tame problems. Wicked problems produce always more than one solution.

"...a world of differing perspectives is one of the fundamental ideas behind the idea of wicked problems".[20] When new information enters the process the catalogue of design issues extend in time. Levels of a process can be modified in singular or plural ways. This effects all three phases of design processes, which are the analytic phase, the creative phase and the executive phase.[21]

It creates a continuous control situation. These forms of process navigation lead to "cycling models", which allow process related persons a differentiated process orientation with interchangeable targets.[22] Through iterative process dynamic solutions of problems emerge.[23] This fundamental idea means a continuous rotating and testing, compacts the possible solution space and leads therefore to an elimination of potential solutions. Relevant solutions occur during a process through permanent testing and re-informing of a process. The resulting solutions are qualitatively equal. The formal expression, structure and behaviour can be at the same time extremely different. Even material performance can be treated at the same abstract level as other components of the process.[24] The mental picture of form can be virtually evaluated,[25] which leads to a mental testing phase and exchange of positions between process involved persons on an abstract level. Categories to order components in terms of hierarchy and relevance are flexible. Components of a design will be added or getting obsolete over time during the process. To systematise complex building structures require dynamic process structures. Processes contain searching operations, which are not primarily, but to a high percentage driven by mathematical definitions. In systematic processes

19 Irlwek, M. (2011). PHD Research Project, Wicked Problem Structure

20 Rittel H. (1972a). ibid

21 Archer B. (1963) In: Dubberly H. ed, How do you design? A Compendium of Models, San Francisco, Dubberly Design Office

22 Haeckel S.H. (2003) In: Dubberly, H. ed (2004). How do you design? A Compendium of Models, San Francisco, Dubberly Design Office

23 Kumar V. (2003) In: Dubberly H. ed (2004). How do you design? A Compendium of Models, San Francisco, Dubberly Design Office

24 Ertas A. & **Jones J.C.** (1996) In: Dubberly H. ed, How do you design? A Compendium of Models, San Francisco, Dubberly Design Office

25 Alexander C. (1971). ibid

different criteria are defined and tested. The effects of defined criteria on the solutions are basic research work. Like form generating processes mathematical formulas are built and variables are implemented, which include unknown factors. This changeability in the equation allows the formal expression to modify. Alterations in the system are directly proportional to formal expression of geometry and structure. Growing complexity in architectonic senses and ongoing exchange of knowledge or a lack of information allows also flexibility between different disciplines.

During design phases feedback is an important part to avoid fixing thoughts and positions in a too early phase. Different connected levels of a process are reassessable through a feedback spiral.[26] The levels of a process can be catalogued in main topics, like environmental aspects, functions, structures, materials and performances. Therefore multileveled issues can be addressed simultaneously. Feedback is an essential mechanism to reflect and modify potential design solutions.

2.2 Mathematics and computer sciences

Mathematic logic helps to search algorithmically for a responsive solution space within a complex system. If more than one solution emerges in an algorithmic process, the formula or mathematic function has too many variables and needs to be informed through definitions of parameters or values. The alternative development in an algorithmic process stops algorithmic calculations because of a lack of or an abundance of information. Algorithmic processes are not able to process solutions. The process must to be started again or it loops.[27] In case of architectonic solutions more than one design solution will emerge. These solutions are similar in terms of quality and problem related properties. Within multivariable systems conditions of stability and instability will be achieved. Stable subsystems are generated through dominance between variable systems. Different stabilising mechanisms affect subsystems. This leads to stabilising the overall system, which is then able to bring up sufficient solutions regarding to the given problem.[28] With generative computation possibilities of modulated typology, not just simple optimised calculations have occurred.[29] Divisions and subdivisions of problems are generated in computational processes. Linking, restructuring and dividing process structures create dynamic and fast processes and new forms of systems. Algorithmic processes are comparable to dynamic design processes and allow logical continuity. Therefore form finding processes and methods are subjected to special regulations through mathematical and dynamic processing. The base for technical and systematic approach for generative form finding out of a dynamic process between computation and argumentation is already existent.

2.3 System sciences connecting brains

New is the approach to connect information, argumentation and decisions not just as communication outside associative computing but to integrate argumentation directly into the process via developing updated design methods. Rittel educed already the APIS (Argument Planning Information System), which should support dynamic - argumentative processes.[30]

During information processes the connection between information, delegation and the value of information are leading to specific decisions between involved

26 Agogino A. (1974). In: Dubberly H. ed (2004). How do you design? A Compendium of Models, San Francisco, Dubberly Design Office

27 Aho A. et al (1983). Data structures and algorithms, Addison-Wes-ley, Reading

28 Rosenbrock, H.H. (1974). Computer-Aided Control System Design, Academic Press, London, pp 117-189

29 Sprecher A., (2005). In: Dubberly H. eds, How do you design? A Compendium of Models, San Francisco, Dubberly Design Office

30 Rittel H. (1980). APIS: A Concept for an Argumentative Planning Information System, S-80-2, Working Paper 324, IGP, Bibliothek Institut für Grundlagen der Planung, Universität Stuttgart

designers. Decisions are directly related to declarations of parameters and values. Which variable has high degrees of flexibility, which ones remain with low degrees of flexibility? Data processing has direct impacts on solution spaces in computational design and links at the same time process related persons to that special design problem.
Wicked problems build therefore automatically a network, based on information systems, combine and ask for required information in a special time frame.
"…each situation is a part of an overall network of knowledge, each time related series exists of parts of components with high degrees of overlapping. The modification is delegated through problems; problems were determined through internal and external information and activation of consolidated knowledge".[31] Just when information is connected systematically, useful knowledge transfer can be activated. Information and knowledge, which is not shared with other process related persons, remain almost useless and cannot extent or help solving problems.

2.4 Platforms of information

According to Rittel and Kunz, knowledge creates in terms of knowledge transfer for the solution finding process an essential "*body of knowledge* that contains the problem to describe huge amount of relations and connections in order to define search strategies for finding solutions".[32] Just a "*body of knowledge*" is not enough. It is much more important, how to combine and connect knowledge and to define information flow processed in the system. To reconnect and recombine knowledge leads to new understandings and therefore changing potential positions within complex lines of argumentation. Processes are driven by evaluation, argumentation and resulting consequences. Consequences can be declared as design decisions and depend on the sum of points of views, which cannot be freed from intuition and subjectivity.[33] Planning and information systems are made of knowledge and transfer of knowledge. Rittel discerns in external and internal knowledge:

- factual knowledge
- deontic knowledge > reflects our conviction
- explanatory knowledge > informs us, find a solution to our problem
- instrumental knowledge > a plan is a semi-ordered amount of instrumental knowledge, which is brought up to the date to resolve a problem. By implementing all these instructions it is expected that the original discrepancy between a piece of factual knowledge and a piece of deontic knowledge about a situation can be overcome
- conceptual knowledge > productivity[34]

Just when knowledge transfer is activated, basic decisions can be created. Rittel´s awareness declares decisions as good as the conviction of the arguments.
"One aspect of planning exists in that way, not to know too early, which kind of solution should emerge. Designers should be educated, to find problems, transform, structure and implement them".[35]
The result of an argumentative knowledge transfer creates a logical platform to generate decisions and instruction for operations.

2.5 Dynamic design methods

Design processes are collaborative and in a communicative way elaborate. Data

31 Rittel H. & **Kunz W.** (1970). Systemanalyse und Informationsverarbeitung in der Forschung, R. Oldenbourg, München
32 ibid
33 Schönwandt, W. (2008). ibid
34 Rittel H. (1972c). Structure and Usefulness of Planning. Information Systems, IGP, Bibliothek Institut für die Grundlagen der Planung, Universität Stuttgart, in Bedrifts Oekonomen, 8, pp 398-401
35 ibid

processing and data flow are just with computational tools democratically manageable. Furthermore design involved persons have different intentions during a design process, which leads to an increasing complexity of data processes.[36] The activation of rich variance is implemented through the diversity of arguments. The extension of an argumentative process to an action orientated digital design process, when techniques and technologies merge, needs coherent logic's and methods. The inner logic of dynamic processes is resulting in arguments, transfer of knowledge and computer based solution containment's. Between persons an universal validity based on process dynamic development and resulting consolidated findings is achieved, when scientific logic emerges. This logic is not free from subjective points of view. The meaning of arguments can be configured in different directions. Design methods are open processes. Strict boundaries are not existent and definitions remain open. Through permanently changing conditions in a process, caused by technical possibilities and changing positions of designers, it is not possible to generate an acknowledged control equipment of relevant criteria. Postulates of meanings and values activate processes of dynamic exchange within systems. The process remains open for inner and outer information. Side effects of developments are interesting because they are unpredictable. Therefore results and possible solutions are not foreseeable and characterise open dynamic processes. Design processes are transparent through democratic discussions. Rittel called that process types "participatory processes".[37] All process developments are generated through an open and transparent process of position exchanges.

It is hardly possible to supply all process related persons with the same information at the same time. Because of the instability of a dynamic process information occurs or gets obsolete in relation to time. Planning processes depend on permanent feedback to react on systematic questions and answers.[38 39] Dehlinger introduced a "time-based-information-system", which departs from sequences of snap-shots of data processing.[40] The result is a network of possible developments of questions and answers and therefore positions. When answers grow to declarations a time based framework for decisions is achieved. Transfers to actions are then possible. The process is now in a state of stability. Through dynamic, continuous developments modification processes emerge even when operations are happening. Modification processes cannot be stopped. Even when a structure is built in real, changing conditions affect functions or structural elements. The question occurs, how can we control dynamic changing conditions? "Control is always relative, never absolute; it has a distorting effect on those who are subjected to it, as well as on those who experience it; and lastly, it has a self-generating effect".[41]

Hierarchical control is the theory of controlling large systems, which are always organised in a distributed hierarchy. In all kinds of hierarchical systems the common feature is the fact that a decision-making process has to be divided. There are several decision-making units in a structure, but only some of them have a direct access to the control system. The other decision-making units are at a higher level on the hierarchy and they define the tasks and co-ordinate the lower units.[42]

Dynamic design methods need to be implemented in systems and subsystems in order to deal with changing conditions, even more in contemporary software

36 Moran T. & **Carroll J.** (1996). Design Rationale: concepts, techniques, and use, Lawrence Erlbaum Associates

37 Rittel, H. & **Webber M.** (1977). Dilemmas in a General Theory of Planning, S-77, IGP, Bibliothek Institut für Grundlagen der Planung, Universität Stuttgart

38 Rittel H. (1980). ibid

39 Schönwandt, W. (2008). ibid

40 Bodack, K.D. et al (1990). Entwurfs- und Planungswissenschaften in Memoriam Horst W.J. Rittel, IGP Bibliothek, Universität Stuttgart

41 Faludi A. (1973). Planning Theory, Oxford, Frankfurt, Pergamon International Library of Science, Technology, Engineering & Social Studies

42 Bentley Systems (2008). Bentley Systems 2009 Generative Components V8i Essentials 08.11.08, USA Patents 5,8.15,415 and 5,784,068 and 6,199,125, Bentley Systems tools. Control mechanisms will change from a tree structure (hierarchical) to a network structure or a combination of both.

2.6 Open feedback processes

Architects and designers are put in the position of process moderators. During a process it is important which information when and from which discipline is linked to the overall information network. Which information has an effect on which participant at a special point? The characteristic of the information system of parameters defines the characteristics and performance of the object. If certain kinds of information are not available at a specific time, the development of object behaviour changes. Continuously testing and evaluating effect conditions and values of parameters. These are main elements of driving an open feedback process. The parametric driven object is regenerating and modifying through manipulation of parameters. If regeneration due to over constraint is not possible any more special software is able to support finding ways to define over constraint parts of the process.[43] Software like “Grasshopper” combined with “Rhinoceros” or “Generative Components” describe ways of actions and therefore decisions graphically. Designers are aware of active connectivity and resulting consequences. The software helps supporting decisions. It asks for special geometrical definitions, for instance when we try to generate a lofted surface we need to inform the component with curves as input parameters, also called arguments in “Generative Components”.

Significant for the finite design is on all levels of decisions, which parameters are set as “key-values” and which connections between them occur. Parametric design allows high degrees of flexibility, freedom of decision generation and therefore argumentative processing to a maximum time based extend. Models are changeable up to the point when they are going to be built. Feedback loops are during the whole process possible. Compared to Rittel´s methodology the process had to be restarted from the beginning. Therefore the freedom of interacting with the system in parametric design opens new methods to interact with parametric software continuously, which can be seen as a great improvement to former process dynamics.

2.7 Dynamic design methods in computational design

Kotnik categorised the use of computer in relation to design processes in three parts. Firstly digital data processing is used to represent architecture. Secondly parametric design is needed to enable dynamic conditions during design processes and thirdly within algorithmic processing it becomes a design tool to generate solutions.[44] Kotnik follows computational design as an extension of non digital design methods.[45] These thoughts can be seen as a quantum leap of processes and opens new possibilities for creative methodological dynamics. Computational design is not driven by formal aspects but by the inner logic of this kind of processes. Oxman classified five categories of digital design models regarding to flexible relations between designers, conceptual thoughts, process dynamic and the design object itself.[46] It is interesting to test performance models in terms of fixed patterns and show how the object reacts. We must declare the expression pattern. A pattern is a combination of how components, parameter, variable and values are processed in a dynamic system. It is important to think about how

43 Burry M. (2003). Between intuition and process: parametric de-sign and rapid prototy-ping. In: Kolarevic B. ed Architecture in the digital age, Design and manufacturing, Spon Press, New York, p 149

44 Kotnik T. (2010). Digital architectural design as exploration of computable functions, International Journal of Architectural Computing, 8:1

45 ibid

46 Oxman R. (2006). Theory and design in the first digital age, Design Studies, 27:3

47 Burry M. (2003). ibid
48 ICD/ITKE Design Seminar Performative Morphology (2010).

these patterns are linked. Even more interesting is the approach in mathematics and parametric design logics. Parametric determinations extend modification processes to a high degree. Through parametric design it is possible to test the behaviour of objects to a maximum. At the moment feedback information just works for the single designer, working on the model actually. Finding argumentative decisions as a result of feedback - information happens mostly outside the digital world. Parametric design (sometimes referred to as associative geometry) software allows the designer to treat a design as one large database adventure where design process decisions are published as histories embedded in the representation of the design in any given instance of its development. Decisions can be revisited and reworked accordingly, thereby potentially relegating techniques of erasure and remodelling to acts of last resort”.[47]
The question occurs, how argumentative mechanisms can be implemented into parametric design processes in order to enable more designers to participate on feedback information. This would be similar to the question, which control tools would work in computational design systems for the whole design team. These questions are essential for the research on design methods.

3 Case Studies

The agenda for the design seminar at the University of Stuttgart was quite ambiguous. The expectations for the final results of student works were to show precise developments of biological systems into architectural material systems in order to construct a temporary pavilion on the site of the university campus. Students and process involved teachers, like experts of the Plant Biomechanic Group of the University of Freiburg analysed first different bionic systems in order to filter scientific findings. Figures 7 to 17 show bionic systems of mature grass weeds, diatoms, lichen systems, sand dollar structures, phyllotaxis geometry's, wood structures and cactus growth.

Figure 7 Leaf cantilever[48]

49 ibid
50 ibid
51 ibid

Figure 8Leaf structure[49]

Figure 9 Lichen structure[50]

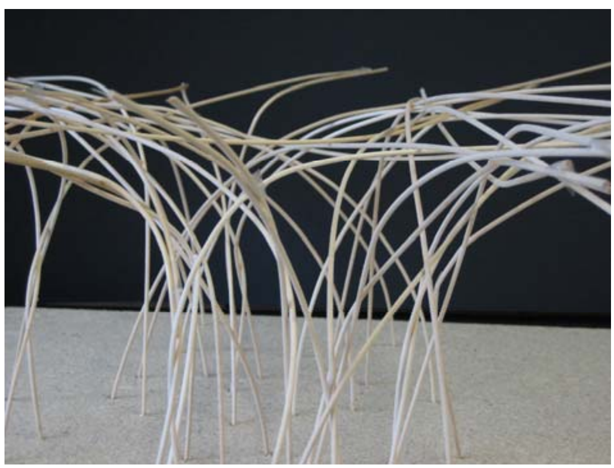

Figure 10 Lichen weaving[51]

52 ibid
53 ibid
54 ibid
55 ibid

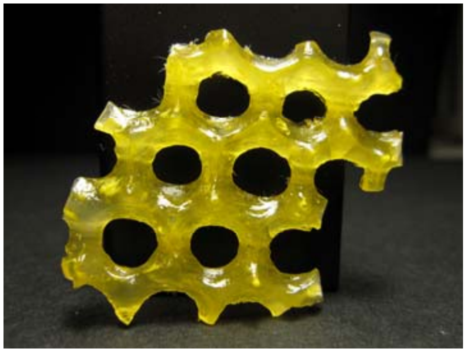

Figure 11 Phyllacanthus imperialis[52]

Figure 12 Diatom structure[53]

Figure 13 Diatom structure[54]

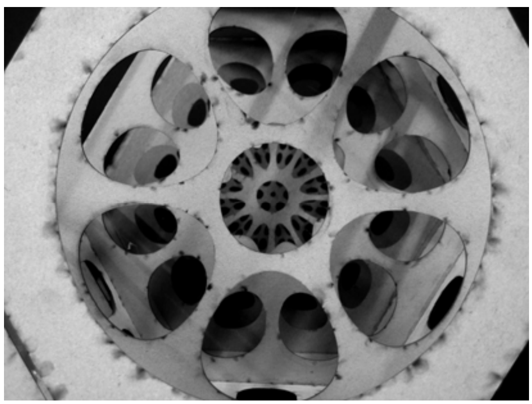

Figure 14 Diatom layers[55]

56 ibid
57 ibid
58 **Irlwek, M.** (2010). PHD Research Project, Extensions of Rittel´s Methodology

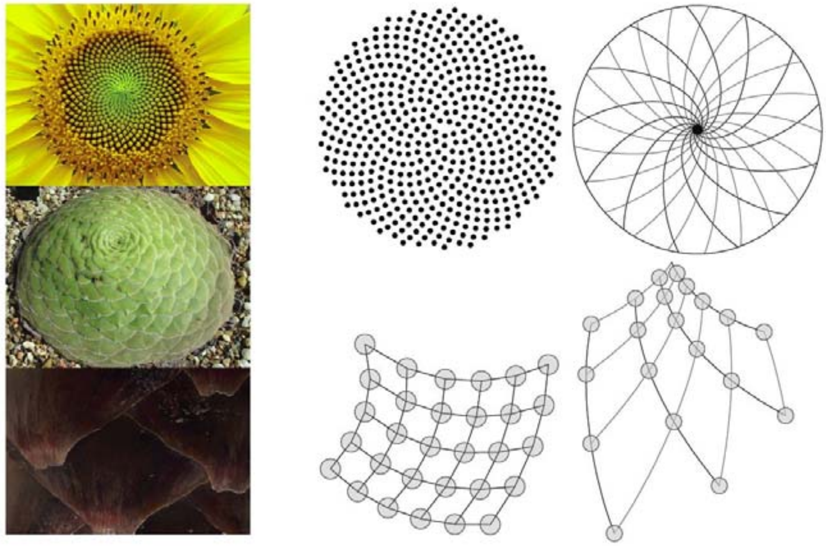

Figure 15 Phyllotaxis structure[56]

Figure 16. Phyllotaxis structure[57]

Figure 17 Surface structures Sean Ahlquist[58]

59 ICD/ITKE Design Seminar Performative Morphology (2010). ibid
60 ibid

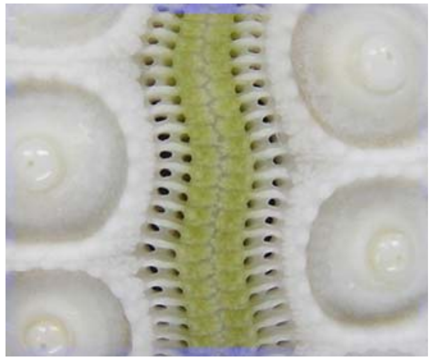

Figure 18 Sand dollar structure[59]

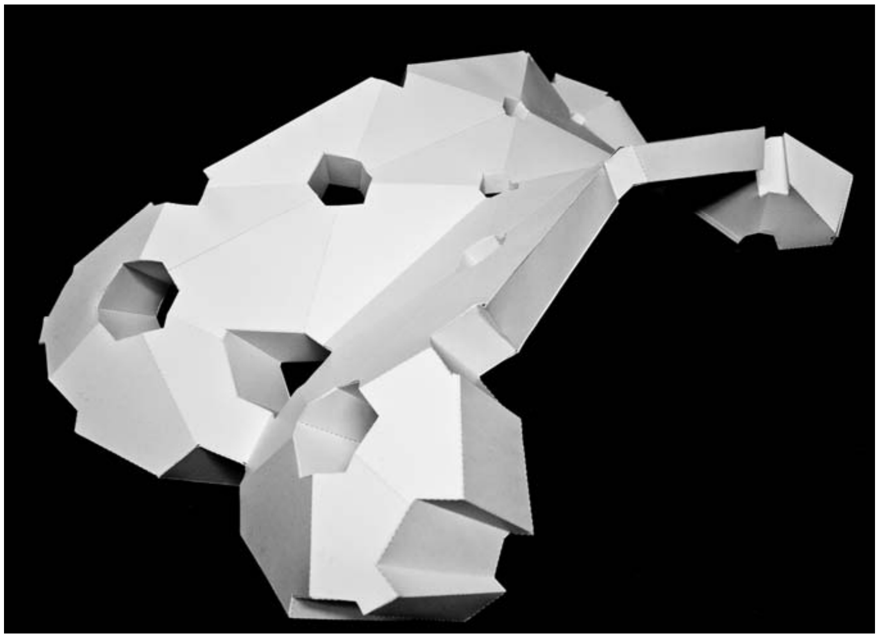

Figure 19 Modified sand dollar structure[60]

The second step focused on transforming reached findings into material systems, which should have specific characteristics, for instances bending behaviour, transition, structural behaviour, load bearing, drainage and architectural parameters, like dimensions, light performance, occupation possibilities, construction settings, scale aspects and aesthetics. Significant for the research is compared to standardised design processes not only the group dynamic exchange of students, teachers, professors and experts, but the extraordinary influence of systematic design strategies based on parametric design software in that case “Rhinoceros 4.0” and “Grasshopper”. Students need to select, which parameter and variable should remain flexible, which one is fixed or which one gets obsolete during the design process. Design decisions were based on computational design strategies, which include rule-based modelling. Even more important for these research projects are implanted filter and constraint systems into the process. Constraint mechanism could be traced in tutorials as argumentative results. The aim is to

61 ibid
62 ibid

transform these filter and constraint logic in software packages in order to be able to select and work with relevant parameters, values and variables to reach relevant solutions and be put in the position to work with wicked problems. The design agenda addressed the transfer of biological constraints into parametric design. The control of data flow was essential to reach relevant results. The complete process was a multi-directional feedback process among process involved persons and computational constraint conditions. Figures 18 to 23 show a selected project for a finger-joined plate structure that is actually built on the campus of the University of Stuttgart in 2011.

This structure was modelled in "Rhinoceros" and "Grasshopper". All plates were pre-manufactured with a five axe "Kuka roboter". The whole process in terms of changing conditions and resulting modifications of variables and parameters remained open to the point of construction on the site.

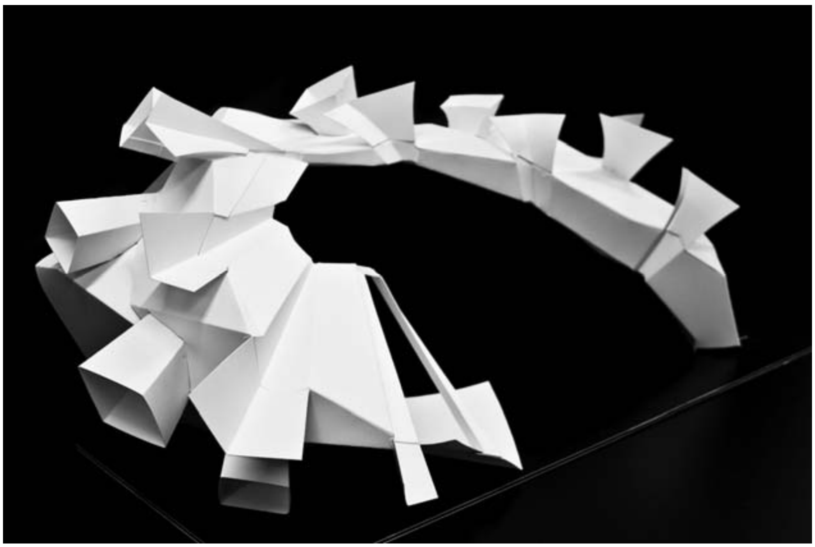

Figure 20 Double interlocking surface structure[61]

Figure 21 Surface structure Oliver Krieg[62]

63 ibid
64 ibid
65 Rittel H. (1972a). ibid

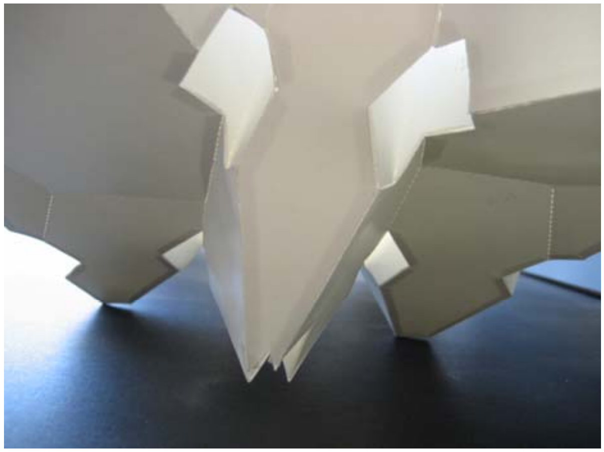

Figure 22 Surface structure Oliver Krieg[63]

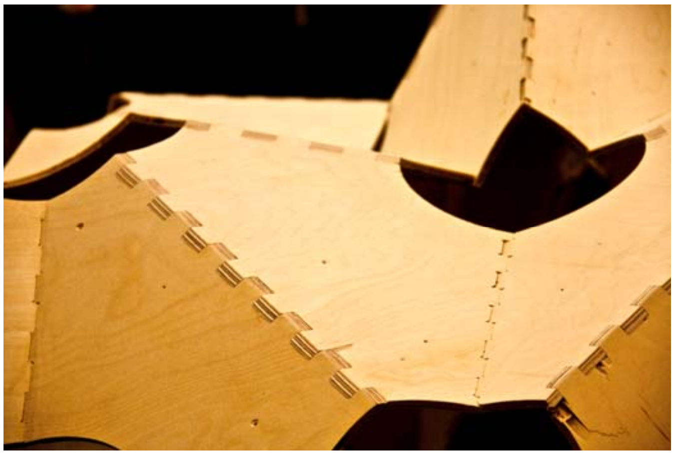

Figure 23 Robotic manufacturing[64]

4 Wicked problems create complex systems

The nature of wicked problems lies in tautologies of the results. It is not possible to find one specific solution. There is always more than one solution.[65] Therefore it is more important to define criteria of relevance. The definition of relevant variables in a system describes a key operation to create stable subsystems. When a system is partially stabilised through its subsystems, criteria of relevance become an important role. To fix some points of possible connections means to activate strategic operations to a given part of the system. One important question occur: Which part of the overall system has to be stabilised? One possibility is to think about connections between subsystems another one is, which components are used (which equations work in the system). All mechanisms need to work in order to stabilise the system and to produce a relevant solution space. The system can operate with internal or external information, for instance with expert knowledge.

Information declares the precondition to be able to start operations. Intentions are parts of information. In a mathematical way intention means to create a formula. We define what should be done. Formulas are built by parameters, variables and defined values. All changes of intentions mean literally to rewrite the formula. Wicked problems create systems and subsystems on different levels of hierarchy and therefore on argumentation and complex formulas. The way designer deals with uncertainty depends on a balance between defining intentions (giving parameters a value, writing formula´s or choosing components as predefined formula's) and setting a variation frame. These mechanisms define already systems and subsystems. The kind of linking subsystems to an overall system is part of relevant mechanisms, which define hierarchy or network based information flow. In a system generated by wicked problems it is essential to work with constraint conditions. These control mechanisms used in a methodological way enable to work even with wicked problems in a sufficient manner.

4.1 Iterative design processing

The results of wicked problem processes are prototypical or generate genotypes. Methods to deal with wicked problems are based on strategic decisions, which allow changes of the tools characters even during the process. Different methodological tools generate different solution spaces and methods to work with and vice versa. If a problem is not solvable, methods need to be divergent and must integrate the ability to learn during the process in order to generate a stable solution space. In computational design it is important to use flexibility generatively in order to control parametric "inputs" in a dynamic process continuously. This offers high degrees of access to data transforming procedures. Constraint conditions can define frameworks for systems caused by wicked problems. To avoid senseless variations, Rittel and Zwicky developed a morphological method (Morphologic Box) to define constraints.[66] [67] They categorised them in different branches:[68]

- Logical constraints: exclude senseless thoughts
- Physical constraints: eliminate contempt against rules of natural sciences
- Technical constraints: relate to realistic methods of technology
- Economic constraints: defines the boundaries of efforts
- Cultural constraints: describes the borders of common acceptance
- Political constraints: clears the expectancy of political feasibility

Each system depends on a hidden logic, which drives network based connections and regulations. Inner and outer conditions change permanently. Therefore systems grow in terms of complexity and non-controllability. Democratic (team based) declarations of constraint conditions combined with algorithmic search are mechanisms, which must be implemented to parametric design processes iteratively in order to control complex systems.

4.2 Computational design as balanced dynamic system

Compared to Rittel´s definition of wicked problems there are no "try-and-error" situations. Every attempt counts and produces prototypical systems and subsystems where undo operations can hardly be implemented.[69] A systematic doubt is needed in order to refresh the system. It is also needed to implement not just principles and theories, it is much more essential to educe methods, how to generate principles and theories. Technical developments improve continuously; therefore technical possibilities are never stable. We can confront technocratic tendencies with methodological strategies.[70] Not just real lines of arguments be-

66 Rittel H. (1982). Der Planungsprozess als iterativer Vorgang von Varietät-serzeugung und Varietätseinschränkung, S-82-2, IGP, Bibliothek Institut für Grundlagen der Planung, Universität Stuttgart
67 Zwicky F. (1966). Entdecken, Erfinden, Forschen im morphologischen Weltbild, München
68 Rittel H. (1972a). ibid
69 ibid

70 Rittel H. (1972b). Die Entwicklung der Technik – Konsequenzen für Bildung und Wissenschaft, Verlag Dokumentation, Pullach bei München, Studiengruppe für Systemforschung eV Heidelberg, Bericht 113, pp 2-17
71 Aish R. (2006). From Intuition to Precision, eCAADe 23, pp 10-14
72 Bentley Systems (2008). ibid
73 Woodbury R. (2010). ibid

tween process-connected persons count but also the exchange between a design team and digital data processed by the system itself as semi-results. Therefore parametric design processes can be seen as design co-operators to solve subproblems in order to create areas of relevance for the overall system. This bilateral connection between design teams and computer based processing extent solution spaces qualitatively. Parametric algorithmic design enables designer to see parameters as argumentative processing tools to work with information. Robert Aish considers that as a balanced system between process specific dynamic, implemented intuition and spontaneity.[71]

5 Exploration within complex systems

Differentiated software inputs enable to interact on different intentions accordingly. The way to measure whether or not the intention has been captured is, if the model behaves in the desired way, when either the formula or the information is altered. Capture design intent means to capture the bits of information, the formula and generate the complete response ultimately. Parametric and associative design systems give users new opportunities for efficient exploration of alternative design through a huge amount of data. For instance “Generative Components” capture design intent by graphically representing both design components and the relationships between them. It enables efficient design exploration and reuse without manually rebuilding the model for each scenario. GC allows designers to work completely graphically or to combine it with scripting. Therefore it is an efficient tool for the design process when associative design emerges from a combination of intuition and logic. Very important for flexible design environments are the abilities to create associative geometry´s through different methods.[72] Every input creates programmed graphs, which can be connected to a bundle. It is possible to show visually argumentative aspects of a process graphically. The model itself will respond to the decisions, which are results of argumentation, positions, intentions and logical combinations. The solution space and the final design are not predictable because of the nature of dynamic problem definition in a complex system. We can claim that analogue argumentative design processes are absolutely similar to argumentative digital design processes. But in computational design we can explore and test solutions in manifold ways in a short time.

“Parametric modelling opens new windows to design. In contrast, parametric systems enable a new set of controls to overlay the basis controls. This creates endless opportunities to explore for forms that are not practically reachable otherwise”.[73]

6 **Discussion: Methodological transfer into computational design**

We need to discuss the implementation of constraint logic to parametric design as a mirrored control tool of team dynamic decisions. Furthermore we need to think about installing this constraint logic as differentiated methods, which are able to modify themselves without loosing control over a complex system.

First it is important to create coherent criteria. Relevant criteria in a process of bundling wicked problems are built by defining orders, rules, patterns and priorities. Priorities can be implemented through an argumentative exchange. Argumentative overlaps form criteria. Specific criteria can be weight loading performance, span dimensions, degrees of open and closed elements, material performances, definitions of length or angle of parts of the structure, which are called "inner" conditions, based on physical or logical constraints. "Outer" conditions are related to intensions. These intensions describe the gap between what is and what should be. The definition of that gap changes during a design process. There we need individual tools to be able to act and react. With software operations in parametric design subjective components (equations) are created, which are able to form individual tools. Parametric design tools change the way designers think. With these tools accordingly it is possible to create very specific associative forms, which are results of predefined or redefined criteria during a process. For instance it is possible to script in Grasshopper with Visual Basics specific components in order to define the amount of input (variables) and output as well as the process formula. Through these operations of creating individual tools, relevant variables can be implemented. The process is yet already in a state of generating variations, which are in the position to create relevant solution spaces. Regarding environmental conditions, associative geometry in parametric design is able to adapt "inner and outer" conditions during the dynamic process with similar mechanisms. Algorithmic calculations and evolutionary algorithms help to test variations in a short amount of calculation steps. The definition of more or less important variables (variable frame) changes subsystems and therefore the overall system. This occurs as visible results in associative geometry as well. To determine importance or priority means literally to create relevant variances in a process of wicked problems. Relevance in architecture is linked to natural sciences, material performances and functional aspects. But there are intentional-argumentative priorities, which are not measurable and therefore more fluent. The fluent character of priorities or chosen criteria result in oscillation of a non defined matrix and link pre-described (individual) components.

We can script our own tools as well as being able to choose and discuss input parameters and expected output. But at the moment we are not really in the position to control data flow. We argue for a constraint mechanism, which is updating itself in an almost self-generating way, because it is connected to feedback loops. Due to a process of wicked problems there is never an absolute stable solution space. Priorities are not fixed because they are related to changing arguments according to time. Design processes and methods are always in a state of flux. The moment of stabilising a system is generated by the condition of arguments and intentions in an almost agreement between objective and subjective intentions. This state is the origin for the associative geometry to be built with real conditions. If it would be possible to top these control mechanisms with self-generating constraint logic mechanisms, we will achieve higher levels of controlling data flow and therefore associative geometry´s. This research opens up different directions how methodologies can be transferred into parametric design processes and is questioning if implemented methods are able to process relevant variances in solution space.

74 Terzidis K. (2006). Algorithmic Architecture, Elsevier, Oxford

6.1 Declaration of priorities and criteria generate relevance

An algorithm is a digital computer procedure, which calculates a problem in countable steps. It is a systematic abstraction of logical principles and develops

generic solutions.[74] The value of algorithmically filtered solutions is the increasing potential of quality regarding to design agenda. Each algorithm is comparable to series of actions. Specific mechanisms and decisions are implemented in algorithmic calculations. In combination with constraint conditions algorithmic calculation help to declare, which variation fulfils aimed criteria. Algorithmic processes generate a framework where the process is going to perform. An algorithm is a form of communication, therefore based on linguistic expressions of a problem. These expressions are translated into syntactic expressions, which are readable for computers.[75] In order to exploit the possibilities through computational design, communicational methods have to be exploited at the same time. Algorithmic processes are precise and allow rationalised copies of logical thoughts.[76]
Terzidis is questioning at the same time the matter of vagueness and dichotomy in creative processes.[77] Comparable to Rittel´s picture of problems as diseases, problems on higher and lower levels influence algorithmic processing through parametric input on different levels synchronically.[78] Constraint conditions combined with algorithmic processes are actively shaping the way of how data interact in a system. At the same time they are able to order and define data flow and generate logical combinations in a system. Algorithms constitute the logic of parametric design and guide data in a strategic manner. A graph exists of nodes and links. The way nodes are linked needs to be methodologically developed.
Thus algorithms need to be linked to constraint systems.

75 Terzidis K. (2008 b). Algorithmic Design: A paradigm shift in Architecture, In: Digital Design Tools 2.
76 Terzidis K. (2006). ibid
77 Terzidis K. (2008 a). Computers and the Creative Process, In: Architectural Computing: The Creative Process, pp 43-50
78 Rittel H. (1972a). ibid

6.2 Treat wicked problems with differentiated methods

Wicked problems contain many aspects, which are not fitting very well to a single system. They exclude each other in some cases. Therefore it is not possible to find one specific target to solve them at once. It is more the search for the common denominator and for changing aims and issues during the process. Wicked problems create complex systems. These systems need to be split into subsystems. An algorithmically constraint based system is able to find solutions for sub-problems, which can be an overlap to other sub-problems. Each sub-problem has a unique property which inhabits different kinds of important tasks. These tasks create a local relevance in the subsystem. Therefore the sum of local relevance creates areas of relevance in the overall system. Areas of relevance are able to generate dominant, stable parts in the complete system. Therefore a system generated by wicked problems needs to be treated with differentiated, self-modifying methods in order to react on changing conditions of relevant areas. The common denominator of design methodologies for wicked problems can be seen as self-regulating control systems consisting of updated constraint logics, which operates on evolutionary algorithmic calculations. Therefore methods must necessarily remain flexible in processes driven by wicked problems. What remains stable is the way how to adapt these methods. Therefore we need to work on a hidden logic behind implemented methods acting as self-generating control tools.

6.3 Methodological modifications

The approach dealing with wicked problems in a satisfying way is only possible due to parametric - algorithmic design processes. Design suggestions are ex-

79 Terzidis K. (2006). ibid
80 ibid
81 Woodbury R. (2010). ibid
82 ibid

posed to an interactive process with computer calculation and design related persons. According to Terzidis mechanisms to declare rational decisions were already implemented in an algorithmic process. Algorithmic processes are generating patterns of unpredictable connective methods. These methods produce a "solution space", where just relevant solutions are going to be formulated.[79] Terzidis declares problem solving processes as processes of identifying and evaluating alternative solutions within this solution space to classify already desirable solutions as even more special or highly adaptable.[80] Computers are extensions of a human ability to design. To predefine problems means already literally to form system structure. Methods in computational design emerge already during structuring problems and argumentation. The interpretation of the nature of problems and their connection to other systems or problems is the root, where parametric-algorithmic design processes already the start. Woodbury categorizes parametric patterns as individual regulative elements. Now we need to extent this approach in order to define the relations between singular patterns and constraint methods.[81]

6.4 Potentials and limitations, advantages, shortcomings

For education and for profession is the research on constraint operation methods a future element for parametric design processes. We can name four parts of a parametric process, which are controllable at the moment. First the declaration of relevant input, like parameters, variables and values, second the way input is processed by the choice of components (equations, formula, functions), third the declaration of output parameter and fourth the link of components in order to create data flow. The fifth aspect needs to be installed as feedback operations and is not there yet.

The combination of the fourth and fifth element can be seen as the basic modules to develop constraint methods. Plug in programmes for existing software can influence and analyse design decisions through modification of data flow. Data flow is then not one directional (tree structured), like in"Grasshopper", but can be re-scripted to a multi-directional data flow. The feedback is not just implemented by the designer but also through the system. The advantage of such small programmes will be awareness about all design decisions according to time. Design decisions become a method through analysing own decisions and also decisions suggested by the system itself.

"Changing the order in which modelling and design decisions can be made is both a major feature of and deliberate strategy for parametric design".[82]

Strategic exploration of huge amount of data is getting very transparent for groups and single designers. Design decisions or group dynamic activities are reported by network based systems. The aim is to get clarity about decision density (which problem is a major problem, which one a sub-problem) and a lack of information or knowledge. The advantage to Rittel´s design methodology is the extension of the systems behaviour itself. Through activities and operations decisions and constraint conditions are implemented from the design team to the system and vice versa from the system to the design team. To control bidirectional data flow is possible with the help of constraint mechanisms.

The limits of a network constraint system are related to the capability of human's ability to work with huge amount of data and data transfer for design decisions.

It is quite difficult to work on design problems and involve all results from other decisions simultaneously. Additional programmes could help structuring information, comparing arguments and decisions, suggesting possible operations and filtering relevant variables and parameters. The feedback loops connect software and design related operations. Methods are transformed through the parametric-algorithmic process itself and correspond with the design team. Their use is prototypically to each given wicked problem. The results are still prototypes, which depend on specific persons, their decisions in relation to information, knowledge and now also from the feedback of systematic methods reported by constraint methods. The most important potential is the interactivity of data exchange and the reported emergence of relevant constrains, build between methodological conditions of the systems and argumentation of design teams.

6.5 Possible improvements for new technologies

To script a programme as a plug in for parametric design software to regulate, control and filter relevant arguments from a group dynamic process can be one possible improvement. This evolutionary constraint methodology is able to declare operations between parametric systems and designers, working on the same wicked design problem. It combines and evaluates graphical activities and finds similar operations. Design decisions could be compared in order to find a common denominator and to see similarities and differences while solving the design problem. Evolutionary constraint methodologies have the potential to improve design processes qualitatively. Future steps are the emergence of relevant variations out of a system, controlled by evolutionary constraint mechanisms. In a process of wicked problems it is first needed to decentralise the system into subsystem, therefore in parts of problems. Secondly systems and subsystems perform in different directions, in bottom up direction, in top to down and/or in cyclic directions. Subsystems have impacts on the overall system and vice versa. Thirdly argumentative interaction between computer and process involved persons are in each state of the process, according to information and data flow results of dynamic definitions of relevant criteria. Fourthly ad hoc decisions due to small intervals of feedback inform the system and restart the process iteratively. Even if every design result is a prototype, methodological patterns emerge during dynamic design processes. This declares them as families of constraint methods. The target is to be able to identify and catalogue these similarities of different kinds of design methods.

Designers can create individual digital constraints to transform constraint conditions to subjective instrumental use additionally. On the one hand the ability to generate adaptable implements opens new ways of construction, forms and structures through the direct connection between arguments and constraint logic´s within computational design. On the other hand it augments possibilities of thinking and emergent updating information systems. It is then for design logic´s possible to generate tailored methodical tools. Therefore it opens up new ways of communication in relation to existing experience in computational design processes compared to conventional digital processes. Through constraint methodologies it will be possible to explore design problems of different disciplines, levels and generations in more coherent ways. Constraint methods can act as the hidden logic behind parametric design procedures.

7 Conclusions: Extension of design methods in computational design

Parametric design, driven by evolutionary constraints methodologies, establishes a feedback loop between sub-solutions and the overall design process in an iterative manner, based on creation of relevant variations and consolidations. Wicked problems require a rapid reaction to design cycles and changing conditions, in order to facilitate agile sequences of testing, decision making and transfer of reactions to associative geometry. We have argued for the introduction of components, work as constraint methods that incorporate not only generative functions (e.g. lofting), but whole design aspects. For example, hidden logic should be made public by clearly defining conditions, characteristics and future behaviours of a design model. Thereby making design decisions transparent means literally to offer design development to an audience and generates democratic discussion, which acts immediate on the design model. Constraint methodologies that give this degree of control may yet not be available, this will require a certain amount of scripting, thereby producing the needed functionality in a form special-tailored to the design process under consideration.

Furthermore, these custom written components may be constrained so that the sequence in which they can be linked together is regulated, thus giving control also over the relation between the process and associated geometry.

To summarise: Strategic exploration in parametric design is possible, if we relate design decisions first to argumentation and second to mechanisms how to direct data flow. These methods act as logic behind design decisions, which should be brought to light, as they form geometric results literally. As a matter of fact, design tools will be able to respond quickly according to changing conditions and democratic argumentation.

Acknowledgements

Image credits are: Figure 7 by Benjamin Busch; Figure 8 by Markus Dehrle and Tobias Pietzsch; Figures 9-10 by Georg Ladurner; Figure 11 by Guoawei Wu;Figures 12-14 by Silvia Funieru; Figures 15-16 Victoriya Nicolova; Figures 17, 21-22 Manuela Irlwek; Figures 18-20 and 23 by Oliver Krieg

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Beckett K.L. and **Shaffer D.W.** (2004). Augmented by Reality: The Pedagogical Praxis of Urban Planning as a Pathway to Ecological Thinking, University of Wisconsin, Madison

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Gorard, S. and **Selwynn, N.** (1999). Switching on to the learning society? Questioning the role of technology in widening participation in lifelong learning, Journal of Education Policy, 14:5, 523-534

Blackman, D.A. (2001). Does a Learning Organisation Facilitate Knowledge Acquisition and Transfer? Electronic Journal of Radical Organization Theory, 7:2 [www.mngt.waikato.ac.nz/Research/ ejrot/Vol7_1/Vol7_1articles/blackman.asp]

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International Journal of
Design Sciences and Technology

Editor-in-Chief: **Reza Beheshti** and **Khaldoun Zreik**

Volume 19 Number 1

Issue Editor: **Gianfranco Carrara**

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1630-7267