A Function-Based Design Approach for Early Planning Phases for Healthcare Buildings

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This contribution introduces a methodology for early planning phases, which is based on a stakeholder oriented analysis of process-related user functions and supports the elaboration of a structural and formal building concept. Also a so-called FunctionsTool is presented, that supports the user oriented development, structuring and grouping of user functions and leeds to a qualified allocation of the functions and their spatial-temporal interdependencies. This tool and also other existing methodical and digital approaches have been evaluated for the complex application-context of hospital planning. So, on a methodological level, a further concept could be drawn up as well as recommendations for the further development of the digital FunctionsTool.

Keywords: *design methodology, stakeholder- and function-based design, webbased tool, hospital planning, early planing phase*

1 INTRODUCTION

Digitization is permeating more and more processes in the construction industry. The Building Information Modeling (BIM) method in particular is seen as having great potential for optimization in terms of planning quality and efficiency. However, with regard to the current component oriented BIM planning practice as well as the available tools, deficits become apparent from a planning methodological point of view: Existing BIM tools are so far mostly focussing on the modeling of concrete building elements, which in part can also be "assembled" from predefined catalogs with BIM objects. Catalog based tools with predefined content, however, often lead to a premature and partly unreflective use of predefined building elements and qualities (efficiency before quality). (von Both 2017).

Assisting methods and tools,supporting a user oriented cooperative specification of the demands and first considerations about structural and building concepts in the early planning phases, do not yet exist on the market. Especially there is a gap on the more abstract functional and conceptual level, which can deliberately widen the solution space and thus enable a more solution open design approach. Here only a few exceptions (for example, the dRofus tool for developing spatial and functional programs) can be found. From this, an urgent need for action can be derived on the part of research (methodology) as well as on the part of application software for the development of cooperative assisting tools and models to support the demand planning and early functional or conceptual planning processes (von Both 2017).

2 THE 'FUNCTION BASED METHODOLOGY' - A GENERALIZED METHODICAL FRAMEWORK FOR A USER AND FUNCTION BASED DESIGN

The 'Function based Methodology' (FbM) describes a methodical procedure model for the early phases of a user- and function-based design. It thus provides an overarching methodological framework and offers specific methods and tools for the individual steps (von Both 2019).

The first step is the development of a holistic target system that makes the impact of planning activities assessable with regard to the entire life cycle of the building - considering also its interactions with the superordinate systems and stakeholders (ReBB 2009) . Relating methods and tools are presented in (von Both 2009, HoSc 2019, EbBR 2010, ReBB 2009).

From the objectives of this superordinate system, the purpose and utility of buildings and thus the specific object-related objectives and functional requirements (including functional performance) of the planning subject can be deduced as cooperative and participatory as possible. Here, it is important to analyse also the value systems, consumer behaviour and development strategies of the clients and also later building users (ReEB 2013). An important mean for the identification of value systems and consumer behavior are also socio scientific approaches of life world studies like the sinus milieu data (von Both, 2006).

Basing on these targets, use related functional requirements of buildings can be determined and taken into account - also with regard to possible organizational, logistic and process-related options (von Both 2019). In this way these interdependencies can be reflected and the topological structure can be transferred into process- and space-efficient spatial structures (von Both 2006) that fullfill the needs of the

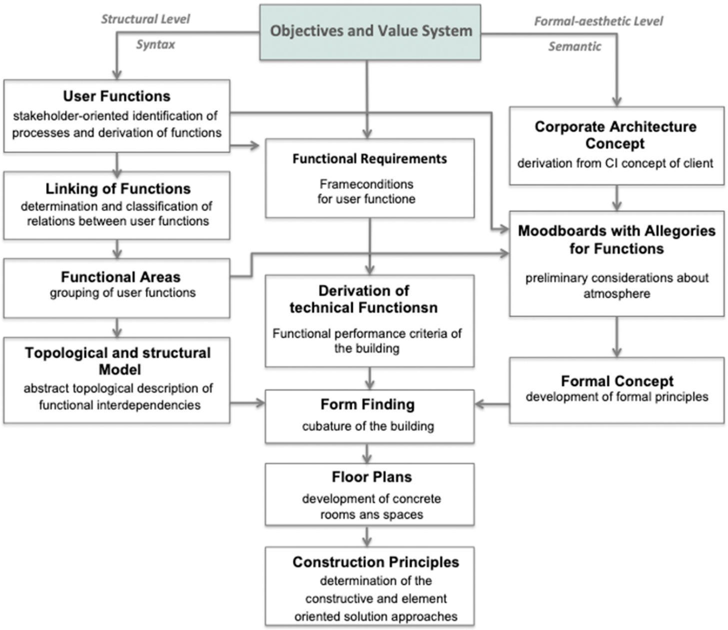


Figure 1
Process-logic of the FbM

specific target group.

The following process model supports the design process on two levels (see figure 1): At the structural level (process shown on the left in figure 1), the development of spatiofunctional topologies and spatial structures takes place, basing on the capturing and organization of the relevant user processes and their interdependencies.

To avoid a pure technocratic procedure, the methodology also offers support on the formal-aesthetic level with the semantic conception and the development of the formal concept and CA Concept (shown on the right).

These steps are carried out in close coordination with the functional requirements for the user functions, which are developed from the projects objectives and the necessary technical functions of the building, derived from them.

On the structural level, the process starts with a stakeholder and user analysis, using methods like stakeholder analysis or stakeholder expectation management (see e.g. Anderl 2016) and the analysis of the activities and proceses of the identified users and their transfer into solution neutral descriptions of user functions.

This process can be supported by a so called "structure matrix' - an adjacency matrix, which helps the architect - in close cooperation and exchange with the client and users - to analyse, qualitatively specify and formalize process related user functions for the different stakeholders (see figure 3). This should be developed in interaction with the functional requirements in the target system (see von Both 2006, Anderl 2016). The analysis and overlay of daily and annual routines of the different users can reveal first relevant correlations. Here, it is very important to specify the functions qualitatively, because it has different spatial consequences.

The next step is the analysis and survey of qualified functional correlations. The quality of the relations in the matrix is configurable and can thus be adapted to the respective project context.

The use related functional relationships can be described, for example, spatiotemporally or in relation to the flow of materials or persons (logistics) and can be mapped in the adjacency matrix (see Figure 3). With regard to sustainability and space-efficiency, the challenge is to identify possibilities for (temporal) spatial overlaps and mixed-use spaces.

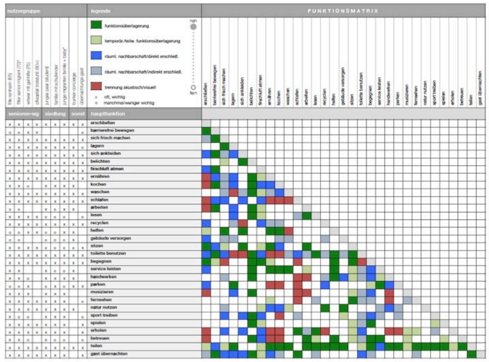


Figure 2
Structure-Matrix for the Analysis of Functional Correlations; student example of a mixed-used housing project, Noel Rabuffetti, 2017

Additional preconditions for the structural formation process in the sense of a systemic approach are considerations about the required technical and physical conditions as well as emissions of the functions with regard to lighting, air conditioning, acoustics and other aspects. An assessment of functional output and required or permitted input of the system dimensions serves as complementary base for the mapping and structuring.

As a first step toward the following space formation, first arrangements of functional groups and areas and for the spatial positioning of functions in the building can be made in a reflected way, based on these identified relations and functional conditions. Here, the functional mapping supports the identification of overlay and flexibility options, which can later be realized, for example, e.g. via so-called cluster flats, a combination of minimized apartments and shared living area and kitchen or via so called joker rooms, which could be assigned to different housing units temporarily.

The planner is, thus, actively encouraged to think about area and space related optimization potentials and can transfer the topological structure of functions into a space efficient floor plan concept. Sustainability assessment systems here also speak about functional equivalence.

To avoid a pure technocratic approach, the building conception in the early design stages also takes place on a semantic level, in which the designer deals with corporate architecture and the adaequate architectural language and the semantic statement the building (Baumberger 2015) as well as the question of the required atmosphere of the functional areas as a basis for later form finding and spatial design. Here the analysed value systems of the customer and target group specific requirements concerning space and architecture perception help to develop a specific customer and user oriented architectural statement and semantic (Flade 2020). So, in parallel to the identification and grouping of functions, the elaboration of suitable formal design principles and atmospheric concepts for the identified functions takes place. Working with mood boards, ideographs and symbols for the functions and functional areas supports an abstract and thus more experimental approach, which has been seen to be able to expand the range of solutions consciously.

The merging of structural and semantic level leads to the reflexive conception of the cubature of the building. Input workshops about form finding methods (YoSK 2016) can enhance the quality of results noticeable. Under consideration of the cubature and the functional topology, now the floor plans can be elaborated. A feedback loop with the stakeholder oriented processes and time schedules can help to evaluate the logistic quality of the floor plans (see figure 3).

Supported by morphological matrices also first ideas about constructive principles can be elaborated. Also on level of the building elements the elaborated strategies for the flexibilisation of space shall be implemented by appropriate constructive solutions flexibly configurable wall elements or furniture.

2.1 FunctionsTool

For the steps of stakeholder related identification and structuring of functions (see FbM in figure 1), a web-based tool has been developed that is also able to support a cooperative approach together with the customers and users.

The so called 'FunctionsTool' supports a user oriented development, structuring and grouping of user functions and allows a qualified representation of the functions and their spatiotemporal interdependencies. The tool automatically generates a structural bubble diagramm - an abstract topological graph schema - from the entries and qualified relations in the adjacency matrix.

Varied predefined qualities of functions relations leed to different length of the relations edges and different forces of attraction of the functions (nodes). Also differentiations of the relations quality in colour allow an easier comprehension and facilitate the prestructuring and grouping of functions as base for the next step, the spatial location of functional areas and the geometric room generation. In addition of the functions name, graphics and ideographs can be stored and represented in the structur nodes.

Figure 3 shows a screenshot of the functionsTool with a students' design project (Hodulak, 2019).

So, the functional and topological structure of the building can be presented and edited in a transparent and ergonomic way by direct visual feedback, so that also non professional customers and users can be involved in the process. This facilitates a reflected spatial allocation of functional areas and the generation of performant layouts.

3 SPECIFIC APPLICATION AND EVALUATION IN HOSPITAL PLANNING

As part of a master's thesis (Sommer 2019), existing specific methods and digital tools for structural hospital planning in early planning phases - including the FunctionsTool - were examined and evaluated during the design process. The master's thesis deals with the method based design of a hospital, whereby special attention was paid to process related, logis-

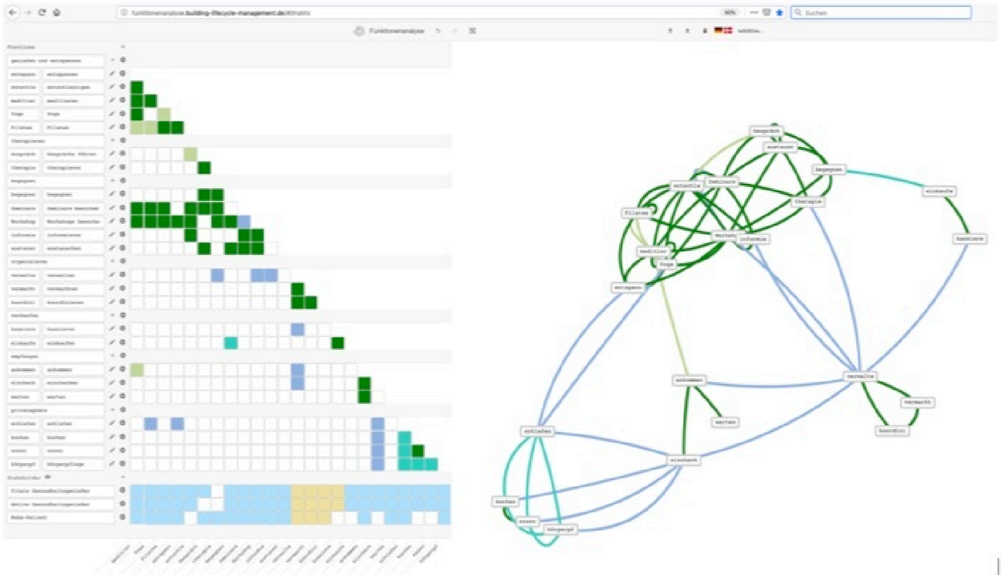


Figure 3
Screenshot of the 'FunctionsTool' with structure matrix and the automatically generated bubble diagram, students project, Conway C and Djokic 2018

tical and business management aspects with regard to to the specific framework conditions in the field of hospital planning.

In addition, there are project-specific requirements. Different treatment focuses and deviating, everchangingmedical processes require specific assessments, flexible planning and transparent handlingof the parameters used.

3.1 Special requirements and processes in hospital planning

The requirements in a hospital are complex and dependencies can usually only be described multicausally. It makes sense, both for experienced planners and for communication with the customer or later user, to have a structural representation of the specific functional and process related dependencies as a basis for joint discussions and user-oriented decisions. ShShort path lengths are a decisive factor for economic efficiency and treatment quality in a hospital. The routes of logistics, staff and patients overlap and in some cases require different connections. It is imperative that these be evaluated on a project specific basis, as there are strong deviations here depending on the treatment strategy and range of services (Stockhorst et al. 2019). However, so called "treatment paths" can be extracted that describe regularities in certain process chains and condition affinities.

In principle, these affinities can be considered at different scale levels. In the classic process of project development of a new hospital, first the targeted clinical performance data are translated into a space and function programme and an operational organisation concept is developed together with the customer. If necessary, this can be brought together in the form of a dependency matrix, similar to the Structure Matrix of the described "Functions Tool". These can be translated into a layout plan, on which the detailed planning for individual rooms is based.

In general, the planning conditions for the specific area of hospital planning can also be adapted and transferred to other building tasks. The hospital essentially serves as an example, as functional dependencies can be clearly described here and are thus well suited as parameters for a tool application.

3.2 Investigate existing digital methods and tools for their suitability for use in hospital planning

First, existing digital tools, especially in the field of generative design, were examined for their suitability in cooperative hospital planning, which can fulfil the specific requirements described above.

The focus was on the generation of area layouts in hospital construction, as this is where there is aparticularly high degree of planning optimisation potential. The basic organisation and dependenciesof functions can be described qualitatively and transferred into functionalities of planning tools. Asimilar matrix as shown in Figure 2 should serve as a basis for further processing.

The field of application for generative design in the area of hospital planning has only been dealt withsporadically. One approach, but only in outline, is the work of Joel Simon. He wanted to optimisehospital floor plans by means of a logarithm based on various parameters. These were mainly pathlengths, but also dependencies between rooms. This resulted in polygons whose areas already corresponded to the target sizes of the rooms. However, he himself came to the conclusion that hisresults were less rational and not directly usable in practice. (see figure 4) (Simon, 2017).

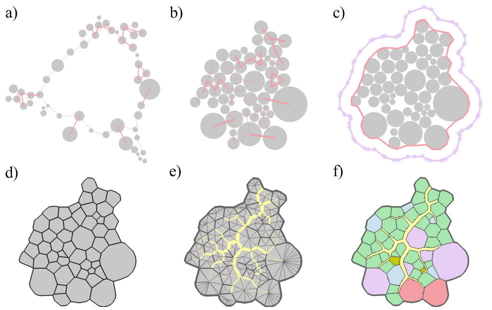


Figure 4
The complete mapping process (Simon, 2017) [3]

Another example is the Early Design Configurator (EDC) of the EU project STREAMER. It generates and presents layouts for hospitals in the design phase. The input parameters for generating layouts are outlines of the building, the already specified room book and design rules. The room floor plans of the planned building are generated automatically with an evolutionary algorithm whose objective function includes the requirements and restrictions of the room book and design rules. But the focus of the structural optimization is on the energy optimisation of the buildings and the operation of an OpenBIM strategy (IFC). However, the process described does not aim to support the process of the collaborative specification and linkage of the functions and functional areas but on the automated generation of finished planned building models, to incorporate the information from the design phase as a Building Information Model into the life cycle of the building. (Geiger et al. 2018)

So it was necessary to look beyond the field of hospital construction for possible applications and tools for function-based planning to find more examples that can be optionally adapted or modified - among others the FunctionsTool.

An initial examination of the FunctionsTool with regard to its use in this specific context showed that it reaches its limits in such complex projects with multi layered functional interrelationships at the level of the entire building, as the multitude of functions can no longer be clearly mapped and handled. The function grouping offered in the tool allows a hierarchisation of the functional structures (e.g. into individual departments and functional areas), but does not allow individual subfunctions of the functional areas to be networked beyond the area or department boundaries. The complex process flows existing in hospital operations can thus not yet be fully mapped in their structure.

In addition, the FunctionsTool - in contrast to the Excel-based predecessor of the object matrix - is not flexibly configurable with regard to the types of relationships. The suggestions provided in the tool, which tended to come from the residential and business sectors, were unfortunately not consistent useful.

Software development in particular is researching and developing in the area of generative design. The aim is to generate different design variants, compare them with each other and select the best design in the course of an optimisation process based on various parameters. Pirouz Nourian developed a plug-in called space syntax for Grasshopper and Rhino applications. Here, arrangements can be generated based on the dependencies of subsequent studies. However, a differentiation of dependencies can hardly be mapped here (see figure 5) (Sommer, 2019; Nourian, 2013 [2]) and the tool seems not to be able to support the involvement of the customer.

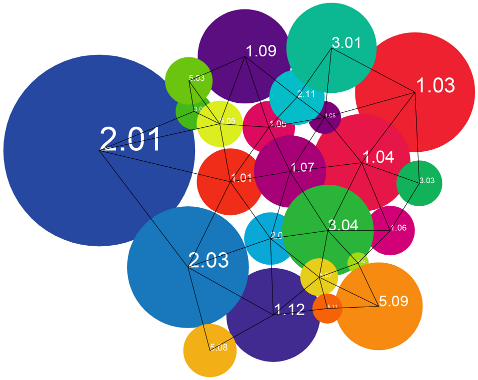


Figure 5 Testing Space Syntax Add-In for Grashopper (Sommer, 2019)

Autodesk also publicises the state of the art in operations, among other things, by using generative methods in the planning of their new office and research centre in Toronto. 10,000 floor plan variations are computer generated and evaluated before selection is made. [1]. What the latter example has over the others is to bring the structure into a spatial-functional context. But also this approach seems not tob e able to support a collaborative process and iteration cycles including the users.

One aim of the master's thesis was, among other things, to find out which decision rules and parameters have to be added to the FunctionsTool, or what a new planning tool has to do in order to be helpful for the application in the hospital. None of the tools shown so far can be easily applied directely to the special requirements of hospitals in the early planning phase.

As a conclusion, it can be said that for the use-case of hospital planning neither in the specific field nor on a generalized level suitable tools exist, which support both the identification of functions and their linkage as well as the transfer into topological structures and layout concepts - especially in the sense of an assisting tool for cooperative planning and involvement of the customer.

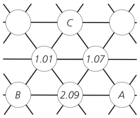
Although the underlying methodological approach of the FunctionsTool (FbM) provides suitable support for the important early processes, it requires further development and adaptation to handle the necessary complexity in hospital planning. Also integrated concepts for supporting the the next planning steps - the spatial positioning of the functional areas - has to be developed.

3.3 Further methodical development basing on the 'Schmigalla'-method

So the next step was to look about existing theoretical methods. However, methods for the parameter based arrangement of individual areas that have some relationship to each other appeared long before the era of computer aided design. One of these methods was developed by Hans Schmigalla in the 1970s. Actually, originating from the planning of factory layouts, the triangular grid method was used to create layouts functionally and parameter based (Schmigalla 1995). After this, a methodological approach was developed in the course of a master's thesis, which not only aimed at sorting and structuring areas, but which can be used as a decision supporting method in the development of the building structure and provides an evaluation of the resulting floor plans at hand.

Thus, this method can be seen as a follow-up and supplement to the above described FunctionsTool and supports the superordinate planning process in the process steps of spatial localization of the tolopogical structure in feedback with the building cubature (form finding) as well as the development of concrete spatial floor plans and layouts.

Linguistic variables, which describe the dependencies of the functional areas on each otherother (e.g. coming from the object matrix of the FbM), are coded with colors and brought together in a table as shown in figure 2. These dependencies are converted into a numerical value, taking into account empirical values (Blöchle, 2014), so that a basis corresponding to Schmigalla's method is available, a numerically describable affinity matrix. A triangular grid is defined for the placement of the functions in space (fig. 6, left). The order of arrangement and position results from the affinity of the function to the already placed functions (fig. 6, right). The result of the calculations is shown in the abstract surface layout as a compact arrangement of the areas in figure 6.



	affinity for 1.05	position A		position B		position C	
		dist.	*logistical effort*	*dist.*	*logistical effort*	*dist.*	*logistical effort*
1.01	*0,47*	*2*	*0,94*	*1*	*0,47*	*1*	*0,47*
1.07	*0,72*	*1*	*0,72*	*2*	*1,44*	*1*	*0,72*
2.09	*0,23*	*1*	*0,23*	*1*	*0,23*	*2*	*0,46*
total	*1,42*	*1,33*	*1,89*	*1,33*	*2,14*	*1,33*	*1,65*

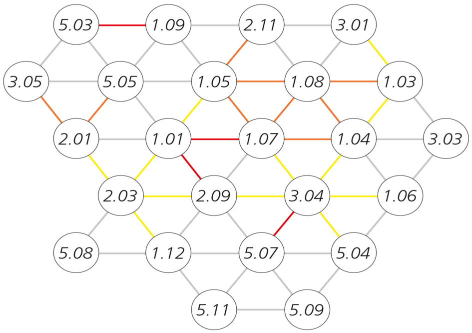


Figure 6
left: triangular grid with the possible positions, right: determination of position, down: result of the first calculation (Sommer, 2019)

This is where the method of Schmigalla ends. In the following, it was supplemented by an affinity (object) matrix as a target value with a distance matrix as an actual value in order to carry out an evaluation. The product of attraction and distance value can be described as the logistic effort in a simplified way.

From the application, it appears that the method worked well. Only individual placements are rated as critical. Almost all affinities are included in the abstract surface layout, which thus depicts a sensible order of the functional locations. Not taken into account here are the sizes of the individual areas and the distances within the structure that change as a result. In addition, no spatially differentiated statement can be made from the ideal order.

3.4 Application and evaluation of the method

The method was applied and further developed in the context of the master student design of a hospital. For this purpose, the method was refined and supplemented in some decision rules in further test runs. The grid was transferred to a previously designed layout, several floors were considered, and fixed points such as entrances and lifts were located. Vertical movements were put in relation to horizontal movements by means of effort studies, and waiting and travel times were also modelled (Blöchle, 2014). In addition, the functions were assigned an extension in the grid according to their actual size in the space programme. Natural lighting requirements were also part of the consideration when placing the functions. Limit values for assessment were adjusted and evaluated according to the new parameters. The evaluation was also carried out in parallel with the placement, so that problem areas could be identified and avoided more quickly. With this basis, a functionally sensible and assessable arrangement within any basic geometry could be achieved within a short time.

CONCLUSION AND GOALS FOR FURTHER DEVELOPMENT

The extended Schmigalla Method has proven to be a good complement to the object matrix and FunctionsTool of the superordinated Function Based Method (FBM) as it builds on the identified and interlinked user functions and transfers them into a spatial context. However, within the scope of the master thesis, only basic methodical concepts could be developed and evaluated, so that the authors see an urgent need for further development.

The following conclusions can be drawn for the further developments of methods and digital tools for the early design stages of hospital projects - especially for the further implementation of the FbM.

The development of the topological structure should not only be unicritically oriented towards logistics. As mentioned in section 2.1, an additional consideration of the flows of system variables (emissions and immissions) could be a useful supplement, for example, to be able to match existing acoustic emissions of certain functions with allowed immissions or to be able to take into account lighting requirements. Thus, also the qualified system flows can influence the attraction forces of the functional bubbles and finally the topology of functional areas.

In order to be able to map the method with regard to the qualification of the logistic performance, the relations have, on the one hand, to be editable and thus adaptable to the specific application (building typology). In addition, the relations should not only be qualitatively describable (as an enumeration or previously defined list of possible values) as it is the case in the FunctionsTool (as well as in the other available approaches of section 3.2), but should be flexibly quantifiable and scalable. By quantified values also the aggregation of different relation types would allow a better multi-criterial structuring.

To allow a better handling of complex functions structures, a better concept for cross-level hierarchization and linking is needed as well as considerations about the structural representation of functions groups (e.g. semantic net instead of hierarchy tree):

The method developed in the master thesis included the step of locating the functions in their spatial context in order to better evaluate and optimize the topology model found. For the superordinated 'Function based Methodology', this means allowing iteration cycles between the two steps (see. Figure 1) 'development of the abstract topology model' and the steps 'formfinding / building cubature' and the development of spatial floor plans.

With regard to the tool level, it became apparent that digital support for the architectural design would also be useful for the downstream process of locating the developed abstract topological models and comparing them with the formal form finding concept and the special cubature and orientation of the building. In this respect, it would be worth considering to what extent it could be useful to include this process in the FunctionsTool in order to be able to compare the abstract bubble diagram with the spatial conditions and thus to include an initial localization and a comparison with studies on form-finding and cubature as a subsequent step.

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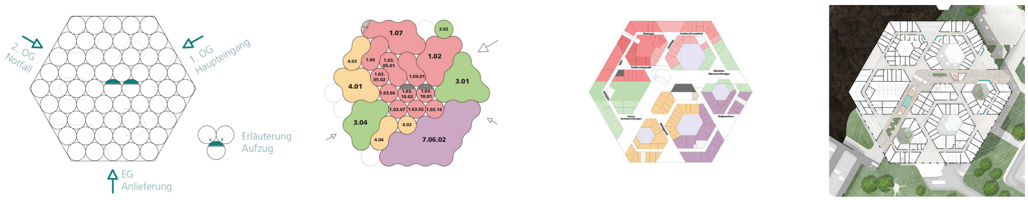

basic grid for method | function layout | room layout | detailed planning

Figure 7
developing a floorplan (Sommer, 2019)

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