SERIOUS PLAY: INTUITIVE ARCHITECTURAL CONCEPTUAL DESIGN WITH IMMEDIATE STRUCTURAL FEEDBACK AND ECONOMICAL AND ECOLOGICAL PERFORMANCE PREDICTIONS

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ABSTRACT: *"Serious Play" (Schraege, M. 1999) is about experimenting with computer models, prototypes and simulations that may lead to innovations. "Play" is related to create alternative design models in a playful way. While exploring, comparing and evaluating the design options, computerized performance predictions can help to "seriously" select and further develop design candidates towards better qualities and performances. We report about an ongoing research project regarding sustainable office design for composite steel-concrete structures. A team at Technische Universität München works on IT-based design aids for the conceptual design phase. We observed that architects traditionally use building blocks for conceptual design of office facilities. Their design also includes a playful process to create, modify and compare competing options. 2D Sketching on paper is their primary choice for creating and communicating design ideas. Later physical models are used to check and verify the design. We want to lever this playful sketching-based approach from the paper drawings and physical models to computer supported volumetric modeling with an implementation in SketchUp that support "Serious Play". Based on initial 2D sketching of foot prints, the architect can create volumetric building blocks, which follow a set of rules implemented in the software from building typology knowledge. While creating and modifying the volumetric architectural model a functional structural design development model is generated in parallel, which serves as input for an automatic structure generator. It will provide instant feedback to architectural design variants with ecologically optimized steel composite systems for the building blocks. The system uses an abstract structure representation that informs about necessary spaces for structural systems and elements. Key performance indicators will be displayed to support performance oriented design. A first prototype is ready for test runs of "Serious play" for conceptual architectural office building design.*

KEYWORDS: *conceptual design, structural feedback, performance predictions*

1. Introduction

Architectural design procedures need to address environmental sustainability issues early in the design processes. The decisions taken in the conceptual phases have a great impact on how the building will perform in respect to the stakeholder needs. Performance oriented conceptual architectural design however needs an engineering, construction and operation feedback. In this paper we present an IT-based approach that supports volumetric modeling of building blocks for office buildings by design sketching in SketchUP. We propose to support the process in providing generated structural systems proposals and display them appropriately in the sketching environment together with a set of performance predictions. For the subsequent design iteration steps (try more options, refine a design or compose different variants) changes in the structural response and the related performance indicators can provide a better informed decision making process. The work is based on two hypotheses:

1. The approach of "*Serious Play*" in conceptual office building design can be supported by a sketching tool for volumetric modeling of building blocks that creates automatic structural systems responses and related performance predictions

2. Composite steel concrete structural systems for office buildings are scientifically understood sufficiently well that we can implement the corresponding construction and design methods for conceptual design in algorithms executable by computers. The goal is to quantify the necessary material quantities of standardized composite building systems in conceptual design sufficiently accurate and to specify the space requirements

for the structural system.

The second hypothesis is based on Donald Knuth’s statement about science and art (Knuth, D. 1974):“*Science is knowledge which we understand so well that we can teach it to a computer; and if we don't fully understand something, it is an art to deal with it. Since the notion of an algorithm or a computer program provides us with an extremely useful test for the depth of our knowledge about any given subject, the process of going from an art to a science means that we learn how to automate something”*

For the concept and the tool implementation, we named the sketching-based volumetric modeler for building blocks *Sustainable Office Designer (SOD)* and the structure generator as *Office Structure Generator (OSG)*. Both applications were developed separately, the *SOD* as a plug-in to SketchUP and the *OSG* as stand-alone application. Currently the *OSG* has been implemented in *SketchUp* and can provide a structural response to a volumetric architectural model in *SOD*. Thus the architects can use one application, which we refer as *SOD*.

We will start our paper with the reflection of the architectural design process, which serves to understand the context in which our sketching volumetric modeler has to work and the necessary requirements for *SOD* and *OSG* to support that a playful design sketching and a better informed decision-making process. Next we introduce the concept of the *SOD* followed by a description of the envisioned workflow for the architectural conceptual design. We introduce the concept of the structure generator *OSG* and how both applications work together. We conclude with an outlook of the next steps.

2. Architectural conceptual Design for Office Buildings

2.1 About the design of Buildings

The design process is an iterative approach and a collective process that involves a variety of actors. The architect has to take this into account with an appropriate design. He must be able to recognize and order the mixture of individual and collective needs and the resulting constraints and develop a tailored “*integrative idea of space”*. This is a complex process that cannot be described as a linear sequence of individual steps, but must be presented as an iterative process.

2.2 Involved Actors and the Constraint of the Building’s Location and Function

To illustrate the complexity, the following is a brief description of the stakeholders and the general conditions to be considered. Who are the actors in this process? First, the builder or the builder community is to be named who will own the facility finally. Particularly for larger construction projects, this group is not always congruent with the group of users who work, live or use the building in another way in the future. There is the large group of indirect stakeholders who nevertheless want to see their interests taken into account: from the neighbors, to the citizens of a community, to our society as a whole. It is responsible for the safeguarding of public welfare and the promotion of a culture of build environment and tries to influence this by norms and rules. All these groups of actors have wishes regarding the future building.

The conditions of the location and function are the constraints every project is subject to:

1. Categorized under the term “location” are all factors that deal with the location of a construction project: the prevailing climate, the orientation of the site, the topography, the site's history, its social context, the existing legislation (blueprints etc).

2. Summarized by the term “function” are all the functional aspects of a specific building, namely: the space program, the operational procedures, the energy budget, requirements for indoor climate and acoustics, statics, etc.

2.3 The playful Approach in Design

As already described, it is the responsibility of the architect to develop an *"idea of space"*, which can integrate this mixture of different constraints and requirements in itself. As designing is a creative process, it always needs a *playful free space*. To maintain this free space, despite the described complex starting position, the architect can use different techniques:

1. He can try - as a result of the analysis - to define system boundaries within which he blithely play
2. Complicating matters are first simplified to enable a more playful approach with individual building

components

3. The architect in a first step can work with alternative design ideas to explore the range of possibilities and spatial relations of individual aspects
4. In Iterative steps the initially set of simplifications are gradually revised and differentiated.

As mentioned above, it is important for the architect to abstract complex relationships in order to preserve the ability to act and play in design. The concept of building typology plays an important role in this respect. The term building type summarizes specific knowledge about functional relationships and the necessary spatial sequences. This knowledge is based more on a mixture of exemplary buildings and experiences than on sound scientific methods. Nor does it represent all the possibilities of design. Nevertheless, it helps the architect for example, in the office building design at a very early stage to link the geometrical dimensions of his “Play Blocks” with the assignment of specific office organizations types.

To integrate the necessary specific discipline knowledge, the designer binds specialists in the process. Since this happens at a relatively late stage, he must be able to imagine and to consider the overall design in advance, in a literal sense to provide space for them. For this he uses his knowledge about building typologies.

With the increasing demands on our buildings, the complexities of their functional conditions rise as well. The demand for ecological performance optimization, structural systems optimization and related the minimization of the fabrication and construction energy, as well as a growing economic pressures require the integration of highly specialized knowledge at a very early stage of the design process. The traditional knowledge about building typologies is not sufficient.

3. Concept of the Design Sketching Tool

According to Eisele 2011, office building can be considered as an assembly of building blocks. For the given conditions of the location and the functions required for an office building, architects use their knowledge about building typologies to create spatial building block sequences that provide the needed functional relationships (see Fig. 1). For different office lay-outs like single offices, group offices, combination of single and group offices, business club and open space offices rules have been derived regarding comfort of use, flexibility for change of office use requirements (i.e. still office use) without the necessity to modify the structure. Among others, the flexibility rules specify: clearance height ranges, widths to depths ratios, distance ranges for internal column rows, etc.

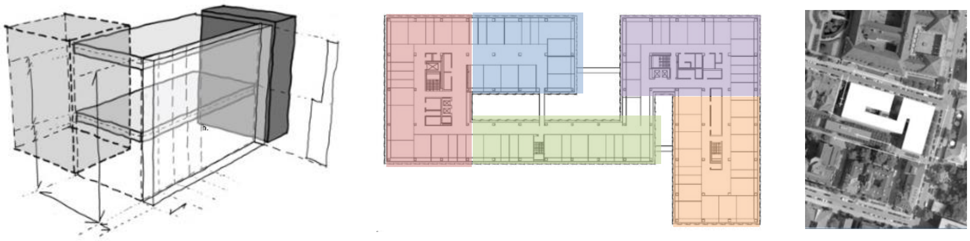


Fig. 1: Office buildings as parametric models in a system of assembled building blocks (from Eisele, 2011)

To support the design processes described above, we developed a Plug-In tool for Google SketchUp that we named “*Sustainable Office Designer (SOD)*” We chose SketchUp, because it is a freely available sketching tool, with intuitive features like easy drawing and loading the geo-position from Google Maps. Furthermore, the included functionalities can be extended easily by scripts written in the programming language Ruby. The extensions have been developed, because the original SketchUp program provides mere geometry interaction and does not support automated approaches to geometry generation. To build a tool that complies with the conventional way of working in early design phases and, most importantly, does not hinder but support the creative process, we implement some design rules defined by the architects involved in the project. These design rules are derived from architectural knowledge about building typology and experience gained from different projects and design studies. They consider different design aspects like the room depth to provide optimal natural lighting or column free spaces to support a minimal amount of flexibility. Furthermore, a number of German design standards for working spaces are considered. As another way to keep things simple, we decided to use as less different functionalities without restraining the freedom of the architect to design what he is thinking of. The functionalities have to be intuitive. Accordingly, the use of numbers and formulas has to be avoided, and therefore we do not attempt the architect to use numbers and formulas. The architect can just focus on the visual appearance of the design.

3.1 Sketching-based Design from 2D Footprint to volumetric Building Blocks Models

The main design constituents are:

- a site plan or a preloaded image of the surrounding environment (e.g. from Google Maps)
- a 2D footprint design sketch
- generated volumetric architectural model of multi-floor building blocks as a vertical extrusion of the footprint
- subtractive volumes for openings and accesses to the building, like entrances and passages
- volume elements for elevators and staircases
- volumes for column free spaces

In the following, we illustrate the prospective workflow for the conceptual design. In a first step, the architect sketches different shapes for the footprint in a preloaded site plan (Fig. 2) or alternatively in a representation of the surrounding environment (Fig. 4), which was uploaded from Google maps. The following hand drawn architectural sketches illustrate both the design workflow by an example of an office building placed next to an existing L-shaped building and as a visual means to define the requirements for the *SOD*. In a second step a volumetric architectural model of the building block will be generated as a vertical extrusion of the selected footprint using the provided parameters e.g. number of floors, office types and flexibility class. The *SOD* will generate the volumetric model by deploying the implemented rules from the architectural building typology knowledge. In parallel a *functional structural design model (FSDM)* is created, which serves as input for the structure generator *OSG*. Depending on the chosen office type the *FSDM* e.g. has a requirement for allowable distance ranges for internal column rows.

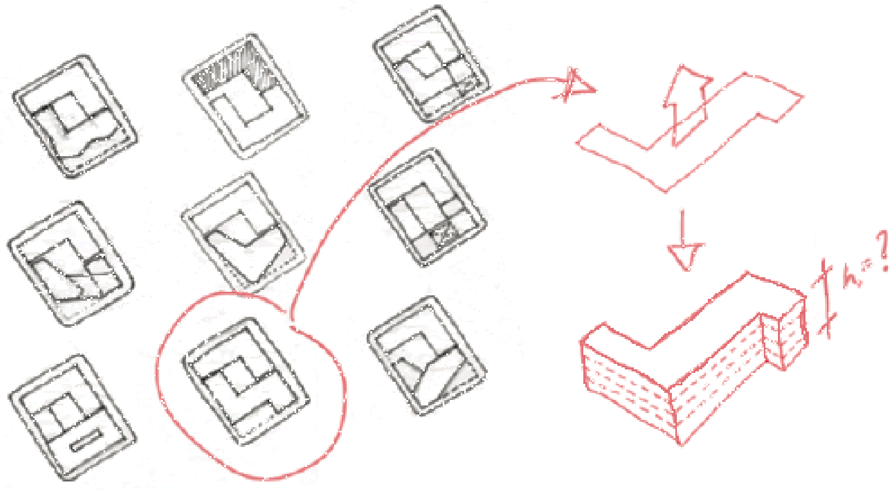


Fig. 2: Variants of 2D footprint design sketches and the generation of volumetric building block models

The architect can now explore the volumetric model in the 3D visualization and compare it visually with other alternatives, which have been designed based on the different foot prints in Fig. 2, left. We are interested to learn in the next research steps, if the computer visualization of the 3D models is sufficient for decision making and has the potential to reduce the need for physical architectural models.

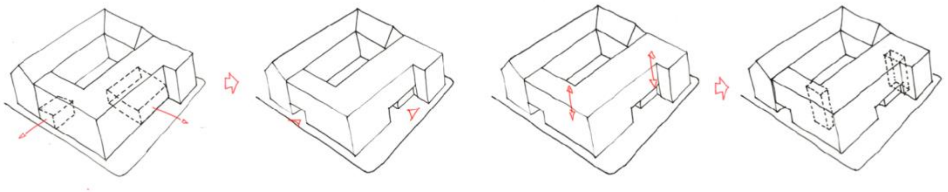


Fig. 3: Sketching and modifying entrances, passages, openings and core elements for vertical circulation

Following the volumetric design of the building block the architect can design the access to the building and the vertical circulation. Again the sketching approach is used to insert subtractive volumes for entrances, passages and openings (see Fig. 3, left) and staircase and elevator volume elements, which can be placed into the building block model (see Fig. 3, right). The designer can add and modify the circulation volumes. Especially the vertical circulation elements in most cases are not part of the steel construction due to the fire safety reasons. In the *FSDM* these volumes are specified as concrete cores containing the staircases, elevators and sanitary installations.

3.2 The playful Approach - conceptual Design Iteration Loops

As already mentioned in Chapter 2, architectural design is a creative, iterative process. The architect can apply different strategies to playful develop conceptual designs. Fig. 4 show typical design loops that involves sketch-based modifications, adjustments etc. and show an example of one design variant in *SOD*.

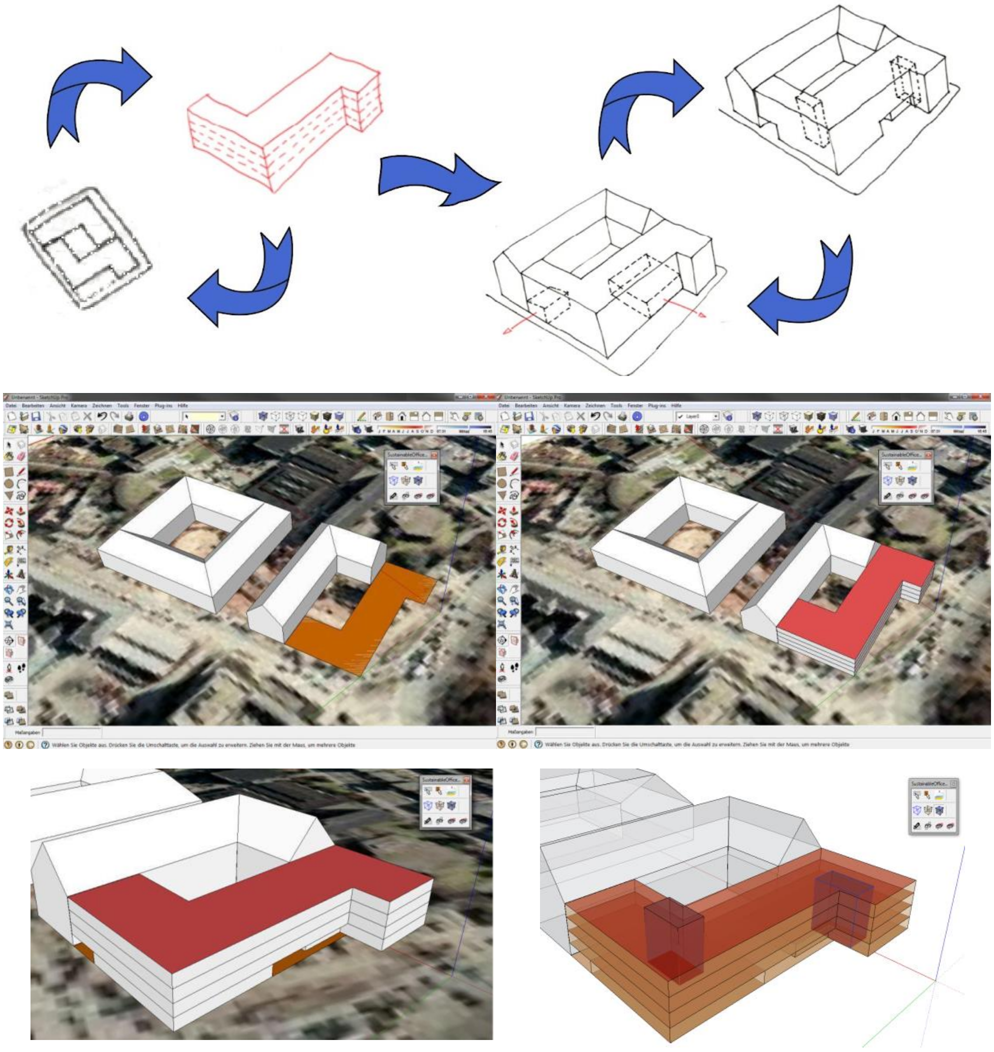


Fig. 4: Iterative design loops and the prospective work flow from a footprint sketch to a volumetric architectural building block model.

3.3 The structural Response to the volumetric architectural Design How to communicate the Essence?

In addition to visually comparing and evaluating the design options we suggest providing instant feedback to architectural design variants with automatically generated, ecologically optimized steel composite systems for the designed building blocks. To communicate the required spaces for the structure an abstract representation is proposed to keep the design model free from congestions. In Fig. 5 top left, an idea of a mixed 3D volume for the architectural design and a 2D grid representation for beams and columns is shown and in Fig. 5 top right the actual implementation in *SOD*. Fig. 5 bottom left displays the transparent architectural building block model and necessary construction height for each floor is displayed inside by a grey volume extruded from the footprint of the slabs. Beams and columns are displayed as grids on the slabs. The last variant shown in Fig. 5 bottom right will be displayed in *SOD* next to the volumetric architectural model. The linear structural elements like beams and columns are shown with their 3D center lines; the slabs are shown as an extruded foot prints with the necessary construction heights.

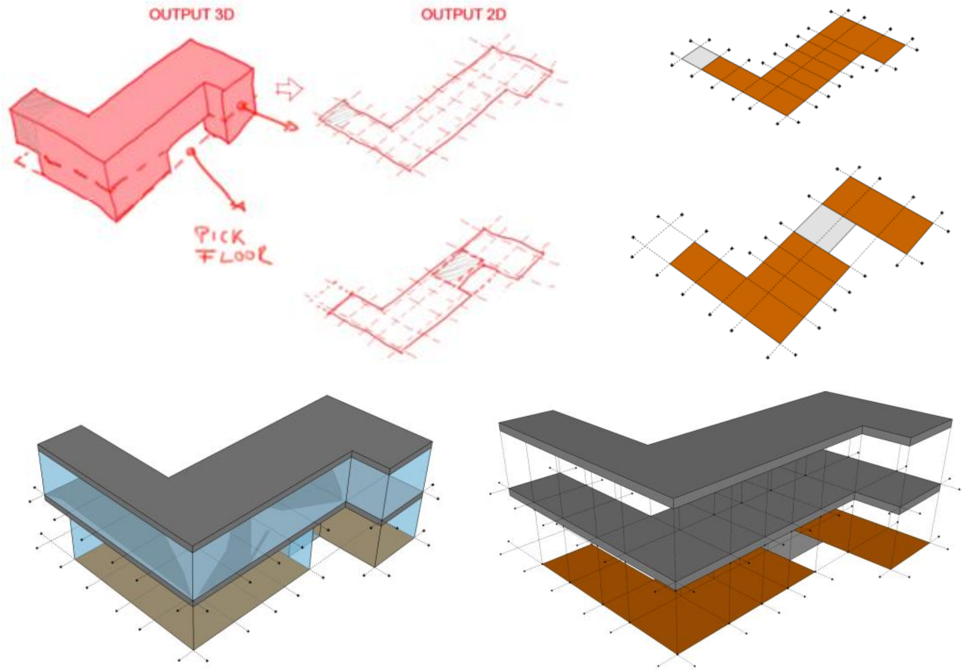


Fig. 5: Structural response to volumetric architectural design. Abstract representations of the structure

From the generated structural system for an architectural volumetric design variant, the necessary material consumption, the ecological footprint to be expected and further performance indicators will be calculated. In a performance view (Fig. 6) a selectable number of design variants can be quantitatively compared to support a better informed decision making process. The necessary structural materials, like concrete, reinforcement steel,

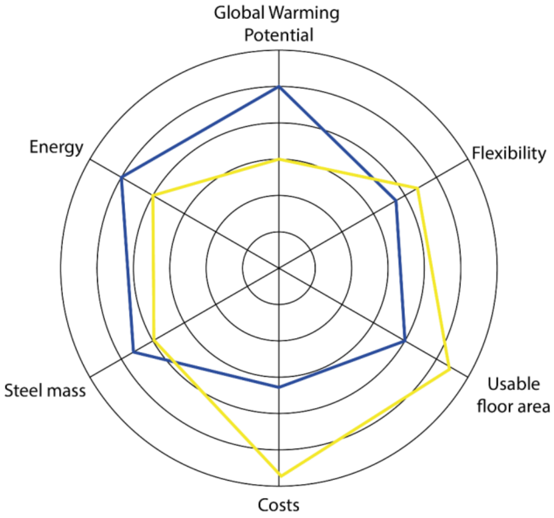


Fig. 6: Design performance view to compare design variants.

structural steel and sheet metal decking are currently the input parameter of for the calculation of the ecological footprint. We plan to add, the coating of the structural steel and the façade system in the future. Thus only a part on the building’s impact on the global warming potentials is covered. The intention of this approach is, to give instant feedback about the structure and façade system related consequences for architectural design variants.

4. From architectural Design to structural Design

The main objective to create a structural systems for architectural conceptual design variants is to assess the necessary materials quantities sufficiently enough that we can create reliable performance predictions. Office buildings with steel concrete composite structure in this respect can be considered as an assembly of several building blocks of office floors as shown in Fig. 1. The footprint of the building block is rectangular or trapezoid. For the same architectural design different composite floor systems (Fig. 7 shows some examples) can be applied. We refer primarily to the primary-secondary composite beam and slab floor system to explain the concept (Fig. 7 in the middle). The other systems have been implemented in the *OSG* as well.

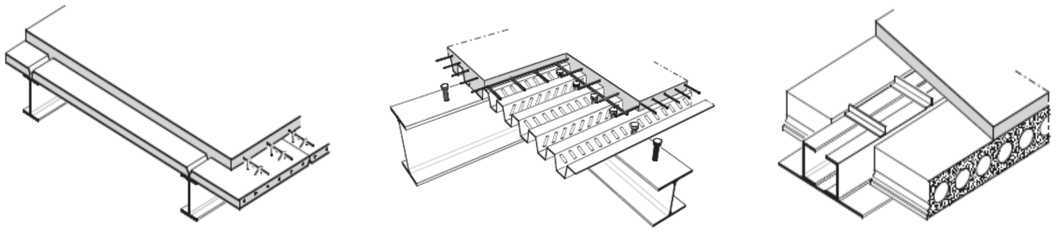


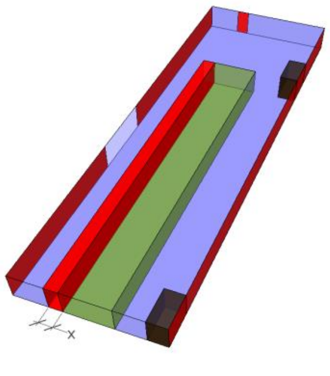
Fig. 7: Composite steel concrete floor system (SZS 2006)

4.1 Parametric structure Definition and design Rules

Design rules from Eurocode 4 (2004) are used for the dimensioning and the verification of building elements. Considering a preliminary structural design, only composite beams, composite slabs and steel/composite columns are verified. The focus is on the vertical load transfer, while bracings and connections between the building blocks are neglected in the approach. To find an appropriate structure for a given volumetric building block design, engineering knowledge has to be implemented to create parametric structural system models that handle the composite system's characteristics, the structural variation possibilities and the structural restrictions well and in a balanced way. Different strategies have been developed for automating the distribution of loads, structural analysis and design verification, reducing the number of different profile sizes or handling specialties like propped constructions. As an example, one characteristic of the primary-secondary composite beam and slab system is to maintain load transfer during the optimization steps. The primary beam serves as continuous multi-span system in one direction and secondary beams are single span beams in the other direction. To cope with the architectural flexibility requirements the parametric model definition was extended such that systems can use either the longitudinal or the transverse direction for the primary beams and apply different span widths for both the secondary and the primary beam.

4.2 Finding an appropriate structural System

Our goal is to find an appropriate structural solution for a given volumetric architectural office building block that has an optimized sustainability performance. For the search we use a Genetic Algorithm (GA) approach that encodes the parametric structural model and uses a single fitness function which estimates the sustainability performance of the designed structure. In the artificial evolution process candidate structural design solution with low fitness values die out and the candidate with the best fitness is chosen.



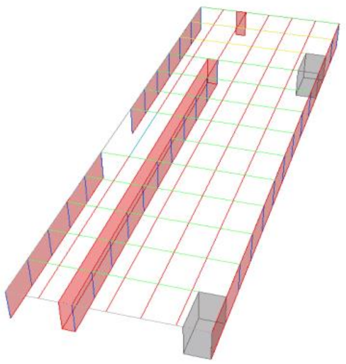


Fig. 8: Functional structural design model (FSDM) left, generated structural model right

As mentioned in chapter 3.1 every time the architect creates or modifies the volumetric model, the *SOD* will create or update a *functional structural design model (FSDM)* see Fig. 8 left. It describes the requirements, specifications and constraints for the structural system to be designed. The *FSDM* serves as an input to the automated structure generator. The structure generator initially applies a parametric composite structural system model with column positions and their possible variation ranges are defined according to the FSDM but the composite floor system type, beam layouts and dimensioning are subjected to the evolutionary search process. The resulting structural design model and the corresponding performance indicators can be inspected by the architect on demand (see Fig. 5 + Fig. 6). The architect may modify the model and possibly introduce additional requirements and restrictions on the structural system, e.g. modify the allowable column locations, demands additional clearance spaces or make justification to the previous designs. In Fig. 8 left, we see the red range as possible location for internal columns, which comply with the rules for flexibility to use different office type lay-outs; a clearance space in green, concrete cores for stairs, elevators and vertical installation spaces for building services and two restricted areas in the left wall and rear area. With the updated FSDM the architect can invoke a modified structure generation (e.g. Fig. 8 right). These architectural-structural design iterations can be continued until the architect finds a satisfied design, which is compliant with the clients' needs.

5. Conclusions and further work

So far, we have the following preliminary results:

- With the first implementation of the SOD in SketchUp, we could prove our concept of levering the paper-based playful conceptual office design to computer supported volumetric modeling that deploys rules from architectural knowledge of building topologies.
- For multi-floor office building blocks with rectangular foot print, we could automatically generate primary-secondary composite beam and slab floor systems with OSG, which have optimized sustainability performances. The structure generator was checked against an existing structural office building design and showed acceptable results. The estimated material quantities were sufficiently accurate for conceptual design
- The structure generator has seamlessly been integrated in the SOD and communicates via a functional structural design model
- The structural systems for volumetric architectural building bloc models can be communicated in different level of abstraction
- A performance design view provides to compare the quantitative key performance indicators of different design variants

The architects of the team will start using the SOD and OSG prototype and use it on three existing office buildings. Their feed-back – especially regarding the playful design and the structural response are used to stabilize and further develop the application. Hopefully we soon might reach the point, when we can systematically test-run "Serious Play" in sustainable office design with larger user groups.

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