The aim of these workshops and conference is to help transfer and spread newly appearing design technologies, educational methods and digital modelling supported by information technology in architecture. By organizing a workshop with a conference, we would like to close the distance between practice and theory.

Architects who keep up with the new designs demanded by the building industry will remain at the forefront of the design process in our information-technology based world. Being familiar with the tools available for simulations and early phase models will enable architects to lead the process.

We can get “back to command”.

The other message of our slogan is “Back to command.”

In the expanding world of IT applications there is a need for the ready change of preliminary models by using parameters and scripts. These approaches retrieve the feeling of command-oriented systems.

Why CAADence in architecture?

“The cadence is perhaps one of the most unusual elements of classical music, an indispensable addition to an orchestra-accompanied concerto that, though ubiquitous, can take a wide variety of forms. By personally selected or invented musical phrases, interspersed with previously played themes – in short, a free ground for virtuosic improvisation.”
CAADence in Architecture
Back to command

Proceedings of the International Conference on Computer Aided Architectural Design

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Faculty of Architecture
Budapest University of Technology and Economics

Edited by
Mihály Szoboszlai
Theme

CAADence in Architecture
Back to command

The aim of these workshops and conference is to help transfer and spread newly appearing design technologies, educational methods and digital modelling supported by information technology in architecture. By organizing a workshop with a conference, we would like to close the distance between practice and theory. Architects who keep up with the new design demanded by the building industry will remain at the forefront of the design process in our IT-based world. Being familiar with the tools available for simulations and early phase models will enable architects to lead the process. We can get “back to command”.

Our slogan “Back to Command” contains another message. In the expanding world of IT applications, one must be able to change preliminary models readily by using different parameters and scripts. These approaches bring back the feeling of command-oriented systems, although with much greater effectiveness.

Why CAADence in architecture?
“The cadence is perhaps one of the most unusual elements of classical music, an indispensable addition to an orchestra-accompanied concerto that, though ubiquitous, can take a wide variety of forms. By definition, a cadence is a solo that precedes a closing formula, in which the soloist plays a series of personally selected or invented musical phrases, interspersed with previously played themes – in short, a free ground for virtuosic improvisation.”

Nowadays sophisticated CAAD (Computer Aided Architectural Design) applications might operate in the hand of architects like instruments in the hand of musicians. We have used the word association cadence/caadence as a sort of word play to make this event even more memorable.

Mihály Szoboszlai
Chair of the Organizing Committee
Acknowledgement

We would like to express our sincere thanks to all of the authors, reviewers, session chairs, and plenary speakers. We also wish say thank you to the workshop organizers, who brought practice to theory closer together. This conference was supported by our sponsors: GRAPHISOFT, AUTODESK, and STUDIO IN-EX. Additionally, the Faculty of Architecture at Budapest University of Technology and Economics provided support through its “Future Fund” (Jövő Alap), helping to bring internationally recognized speakers to this conference. Members of our local organizing team have supported this event with their special contribution – namely, their hard work in preparing and managing this conference.

Mihály Szoboszlai
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<table>
<thead>
<tr>
<th>Name</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdelmohsen, Sherif</td>
<td>Egypt</td>
</tr>
<tr>
<td>Achten, Henri</td>
<td>Czech Republic</td>
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<tr>
<td>Agkathidís, Asterios</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>Asanowicz, Aleksander</td>
<td>Poland</td>
</tr>
<tr>
<td>Bhatt, Anand</td>
<td>India</td>
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<tr>
<td>Braumann, Johannes</td>
<td>Austria</td>
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<tr>
<td>Celani, Gabriela</td>
<td>Brazil</td>
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<tr>
<td>Cerovsek, Tomo</td>
<td>Slovenia</td>
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<tr>
<td>Chaszar, Andre</td>
<td>Netherlands</td>
</tr>
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<td>Chronis, Angelos</td>
<td>Spain</td>
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<td>Dokonal, Wolfgang</td>
<td>Austria</td>
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<td>Estévez, Alberto T.</td>
<td>Spain</td>
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<td>Fricker, Pia</td>
<td>Switzerland</td>
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<tr>
<td>Herr, Christiane M.</td>
<td>China</td>
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<tr>
<td>Hoffmann, Miklós</td>
<td>Hungary</td>
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<td>Juhász, Imre</td>
<td>Hungary</td>
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<td>Jutraz, Anja</td>
<td>Slovenia</td>
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<td>Kieferle, Joachim B.</td>
<td>Germany</td>
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<tr>
<td>Klinc, Robert</td>
<td>Slovenia</td>
</tr>
<tr>
<td>Koch, Volker</td>
<td>Germany</td>
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<tr>
<td>Kolarevic, Branko</td>
<td>Canada</td>
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<tr>
<td>König, Reinhard</td>
<td>Switzerland</td>
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<tr>
<td>Krakhofer, Stefan</td>
<td>Hong Kong</td>
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<tr>
<td>van Leeuwen, Jos</td>
<td>Netherlands</td>
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<td>Lomker, Thorsten</td>
<td>United Arab Emirates</td>
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<td>Lorenz, Wolfgang</td>
<td>Austria</td>
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<td>Loveridge, Russell</td>
<td>Switzerland</td>
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<td>Mark, Earl</td>
<td>United States</td>
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<td>Molnár, Emil</td>
<td>Hungary</td>
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<td>Mueller, Volker</td>
<td>United States</td>
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<tr>
<td>Nérie, László</td>
<td>Hungary</td>
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<tr>
<td>Nourian, Pirouz</td>
<td>Netherlands</td>
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<tr>
<td>Oxman, Rivka</td>
<td>Israel</td>
</tr>
<tr>
<td>Parlac, Vera</td>
<td>Canada</td>
</tr>
<tr>
<td>Quintus, Alex</td>
<td>United Arab Emirates</td>
</tr>
<tr>
<td>Searle, Mark</td>
<td>Hungary</td>
</tr>
<tr>
<td>Szoboszlai, Mihály</td>
<td>Hungary</td>
</tr>
<tr>
<td>Tuncer, Bige</td>
<td>Singapore</td>
</tr>
<tr>
<td>Verbeke, Johan</td>
<td>Belgium</td>
</tr>
<tr>
<td>Vermillion, Joshua</td>
<td>United States</td>
</tr>
<tr>
<td>Watanabe, Shun</td>
<td>Japan</td>
</tr>
<tr>
<td>Wojtowicz, Jerzy</td>
<td>Poland</td>
</tr>
<tr>
<td>Wurzer, Gabriel</td>
<td>Austria</td>
</tr>
<tr>
<td>Yamu, Claudia</td>
<td>Netherlands</td>
</tr>
</tbody>
</table>
Contents

14  Keynote speakers

15  Keynote
15  Backcasting and a New Way of Command in Computational Design
    Reinhard Koenig, Gerhard Schmitt
27  Half Cadence: Towards Integrative Design
    Branko Kolarevic

33  Call from the industry leaders
33  Kajima's BIM Theory & Methods
    Kazumi Yajima

41  Section A1 - Shape grammar
41  Minka, Machiya, and Gassho-Zukuri
    Procedural Generation of Japanese Traditional Houses
    Shun Watanabe
49  3D Shape Grammar of Polyhedral Spires
    László Strommer

55  Section A2 - Smart cities
55  Enhancing Housing Flexibility Through Collaboration
    Sabine Ritter De Paris, Carlos Nuno Lacerda Lopes
61  Connecting Online-Configurators (Including 3D Representations) with
    CAD-Systems
    Small Scale Solutions for SMEs in the Design-Product and Building Sector
    Matthias Kulcke
67  BIM to GIS and GIS to BIM
    Szabolcs Kari, László Lellei, Attila Gyulai, András Sik, Miklós Márton Riedel
Section A3 - Modeling with scripting

Parametric Details of Membrane Constructions
Bálint Péter Füzes, Dezső Hegyi

De-Script-ion: Individuality / Uniformity
Helen Lam Wai-yin, Vito Bertin

Section B1 - BIM

Forecasting Time between Problems of Building Components by Using BIM
Michio Matsubayashi, Shun Watanabe

Integration of Facility Management System and Building Information Modeling
Lei Xu

BIM as a Transformer of Processes
Ingolf Sundfør, Harald Selvær

Section B2 - Smooth transition

Changing Tangent and Curvature Data of B-splines via Knot Manipulation
Szilvia B.-S. Béla, Márta Szilvási-Nagy

A General Theory for Finding the Lightest Manmade Structures Using Voronoi and Delaunay
Mohammed Mustafa Ezzat

Section B3 - Media supported teaching

Developing New Computational Methodologies for Data Integrated Design for Landscape Architecture
Pia Fricker

The Importance of Connectivism in Architectural Design Learning: Developing Creative Thinking
Verónica Paola Rossado Espinoza

Ambient PET(b)ar
Kateřina Nováková

Geometric Modelling and Reconstruction of Surfaces
Lidija Pletenac
Section C1 - Collaborative design + Simulation

Horizontal Load Resistance of Ruined Walls Case Study of a Hungarian Castle with the Aid of Laser Scanning Technology
Tamás Ther, István Sajtos

2D-Hygrothermal Simulation of Historical Solid Walls
Michela Pascucci, Elena Lucchi

Responsive Interaction in Dynamic Envelopes with Mesh Tessellation
Sambit Datta, Smolik Andrei, Tengwen Chang

Identification of Required Processes and Data for Facilitating the Assessment of Resources Management Efficiency During Buildings Life Cycle
Moamen M. Seddik, Rabee M. Reffat, Shawkat L. Elkady

Section C2 - Generative Design -1

Stereotomic Models In Architecture A Generative Design Method to Integrate Spatial and Structural Parameters Through the Application of Subtractive Operations
Juan José Castellón González, Pierluigi D’Acunto

Visual Structuring for Generative Design Search Spaces
Günsu Merin Abbas, İpek Gürsel Dino

Section D2 - Generative Design - 2

Solar Envelope Optimization Method for Complex Urban Environments
Francesco De Luca

Time-based Matter: Suggesting New Formal Variables for Space Design
Delia Dumitrescu

Performance-oriented Design Assisted by a Parametric Toolkit - Case study
Bálint Botzheim, Kitti Gidófalvy, Patricia Emy Kikunaga, András Szollár, András Reith

Classification of Parametric Design Techniques
Types of Surface Patterns
Réka Sárközi, Péter Iványi, Attila Béla Széll
Section D1 - Visualization and communication

Issues of Control and Command in Digital Design and Architectural Computation
Andre Chaszar

Integrating Point Clouds to Support Architectural Visualization and Communication
Dóra Surina, Gábor Bödő, Konsztantinosz Hadzijanisz, Réka Lovas, Beatrix Szabó, Barnabás Vári, András Fehér

Towards the Measurement of Perceived Architectural Qualities
Benjamin Heinrich, Gabriel Wurzer

Complexity across scales in the work of Le Corbusier
Using box-counting as a method for analysing facades
Wolfgang E. Lorenz

Author’s index
Keynote speakers

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Stereotomic Models In Architecture
A Generative Design Method to Integrate Spatial and Structural Parameters Through the Application of Subtractive Operations

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Abstract: This paper introduces a generative design method for architecture grounded on the stereotomic approach. The method is based on the application of the Boolean subtraction operation to integrate spatial and structural parameters in the conceptual phase of the design process. Working on a three-dimensional form, which is displayed and studied as a solid mass with the help of a solid modelling software, the architect is able to hollow it out using subtractive operations to generate interior spaces in the form of spatial voids. This process can be applied in an iterative way; at each step, the portion of the solid mass remaining after the application of previous operations is further hollowed out. The method takes advantage of the potential offered by contemporary digital tools to generate and explore multiple design variations.

Keywords: generative design, conceptual design method, stereotomic approach, subtraction operation

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INTRODUCTION
“Architects think constructively; that is, the principles they apply are conceived in generative terms. The notion of design as computation captures this constructive attitude and indicates, at the same time, basic possibilities for utilizing the generative power of computers in design education” [5]. According to Ulrich Flemming, architectural design can be regarded as a form of computation, a generative process that transforms the initial idea into the final building through the application of successive operations. Following this approach, William Mitchel highlights the appropriateness of using Boolean operations (i.e. union, subtraction and intersection) in solid modelling since they provide the necessary path from the simplicity of a vocabulary of elementary solids to three-dimensional complex forms [8]. Within the field of architecture, of particular interest is the subtraction operation, which has the potential to be employed to hollow out interior spaces from an initial solid mass. Based on this operation, a generative design method for architecture is here introduced, which makes use of the stereotomic approach to integrate spatial and structural parameters in the conceptual phase of the design process.
THE STEREOTOMIC APPROACH

On the one hand, as described by Robin Evans, stereotomy (or the science of cutting solids) was a Seventeenth Century French rubric under which were gathered several existing techniques including stonecutting [4]. According to Evans, “The basis of stonecutting was the trait, a collection of layout drawings used to enable the precise cutting of component masonry blocks for complex architectural forms, especially vaults”. From this perspective, recent researches can be found that explore the application of stereotomy to the analysis or design of vaulted systems [10].

On the other hand, in the words of Francesco Cacchiatore, “the term stereotomic, from the Greek stereos (solid) and tomia (cut), introduces an idea of building, which is not conceived as the assemblage and juxtaposition of elements typical of the tectonic approach, but rather as the gradual removal of matter from an initial shape”. Based on this point of view, the application of the stereotomic approach to architecture results in the generation of monolithic and compact forms, where the individual parts cannot be discerned from the whole and in which the removal of matter produces the intended architectural spaces [1]. From this perspective, if the tectonic approach puts the emphasis on the constructive and technical aspects of the building and on the expression of the detail, the stereotomic approach is grounded on the generation of the voids and on the definition of the boundaries of the building. In this way, the accumulation and distribution of matter produces at the same time both space and structure.

THE POCHÉ IN ARCHITECTURAL DESIGN

Subtractive design methods in architecture and the stereotomic approach in particular, result in the generation of a poché, both in its meaning of rendering technique and a compositional device [5]. Poché is a term introduced by the École des Beaux-Arts of Paris to define the hatched texture used to differentiate the massive elements and the residual spaces drawn in architectural plans. According to Jacques Lucan, “with construction by masonry of piers and load-bearing walls, the poché helped to bond rooms of varied geometry by a sort of spatial stereotomy” [7]. A modern approach to the use of the poché as a tool for the formal analysis of architecture emerges in the theoretical work of Robert Venturi [12] and Colin Rowe [11]; this was then further developed by Peter Eisenman. Within his research on the formal basis of modern architecture, Peter Eisenman defines poché as an interstitial entity, an articulated solid mass between two void conditions, either between an interior and an exterior space or between two interior spaces. “Such a condition of space might require a process which could begin from a process defined as spacing rather than a forming. … The interstitial, then, is the result of a process of extraction which produces a figural as opposed to a formal trope, and it exists as a condition of spacing as opposed to forming” [2]. In the design approach supported by Eisenman, all those elements (such as the program and the site) that are not directly related to a formal process have no real relevance from an architectural point of view.

According to Eisenman, among these negligible elements is also the structure, which consists in those solid elements such as beams and columns that are confined inside the interstitial spaces.

Another remarkable use of the poché in contemporary architecture can be found in a series of projects developed by Rem Koolhaas in the early ’90s; here the Venturian poché is applied to represent the idea of spatial voids hollowed out from a solid. Actually, in some of these projects physical models are built as sculptural and three-dimensional versions of the poché [6]. On the one end, like in the case of Eisenman, the structural elements are confined within the interstitial spaces and materialized in the form of beams, columns and trusses. On the other hand, as opposed to Eisenman, in the design approach promoted by Koolhaas the program represents the driving force of the process. In fact, Koolhaas compares the work of the architect to the one of the screenwriter, since “both processes are based on editing, on the art of creating programmatic, cinematographic or spatial sequences” [7].
FORMALIZATION OF THE DESIGN METHOD

In light of the design approaches introduced by Eisenman and Koolhaas, the aim of the present research is to define a design method for architecture that is grounded on the stereotomic approach. The proposed design method consists in the production of a three-dimensional poché at the scale of architecture through the iterative application of simple geometrical operations, specifically Boolean subtraction, on an initial solid mass. This eventually leads to the generation of a stereotomic model, where spatial voids are contained within an interstitial solid mass. In this way, the solid mass becomes an active element of the architectural design process, with the potential to be activated by incorporating both spatial and structural parameters from the early stages of the process. In its current state, the method is material independent and it is fully developed in three-dimensions. Furthermore, it takes advantage of the potential offered by contemporary digital tools for solid modelling to generate, transform and proliferate multiple design solutions. The design method is grounded on three main steps (generation of the stereotomic model, evaluation of the static stability and hierarchical iteration), which are not intended to be implemented in a linear sequence; in fact, after the first iteration, it is possible to re-execute them following a non-sequential order.

Step 1: Generation of the Stereotomic Model

The main aim of the proposed design method is the generation of interior spaces and the control of their spatial qualities (such as proportion, lighting condition or visual appearance). Therefore, based on a specific architectural program, the first step of the process is undertook to define, formalize and adjust the interior spaces in the form of spatial voids. The spatial voids are then subtracted from a solid mass to generate a stereotomic model.

Generation of the Spatial Voids

In line with the design approach conceived by Koolhaas, the proposed method requires the definition of specific programmatic requirements, such as a set of activities to be accommodated within the building, to initialize the design process. Afterwards, spatial concepts associated to the activities defined in the program are developed. These spatial concepts are then translated into volumes, here defined as spatial voids (SpV), which are the interior spaces where the various activities defined in the program take place (Fig. 1). With the help of a solid modelling software, the volumes representing the spatial voids are independently generated in three-dimensions according to the specific design requirements. The relevance given by the proposed method to the spatial voids follows from Eisenman’s design approach; according to him “volume is the dynamic condition of space” and, consequently, “the generating property of all architectural forms is volume, since architecture alone among the plastic mean of expression demands comprehension both internally and externally” [3].

Furthermore, to each spatial void is associated an implicit negative weight. The latter is represented by a force $R_i$ (Fig. 1), whose length is proportional to the volume of the spatial void, whose points of application is the volume centroid and whose direction is opposite to gravity. The introduction of a negative weight can be explained considering that each spatial void will be subsequently subtracted from the initial solid mass; that is, the weight of the solid mass will be reduced by an amount proportional to the sum of the volumes of the spatial voids.
**Generation of the Solid Mass**

After the spatial voids have been defined, the initial *solid mass* (M) has to be modelled (Fig. 2A). This solid mass represents the bounding volume within which the interior spaces can be allocated. The geometry of the solid mass can be modelled freely following a particular formal exploration or in relation to specific boundary conditions of the site; its volume could coincide, for example, with the maximum buildable volume regulated by the urban code of the site.

The weight of the solid mass is described by a force $R_m$, whose length is proportional to the volume of the solid, whose point of application is the volume centroid of the solid itself and whose direction is the same as gravity.

**Articulation and adaptation of the Spatial Voids**

The next sub-step of the process is related to the articulation and adaptation of the spatial voids within the solid mass (Fig. 2B). This consists in the definition of a topology that enables to create relationships between the individual spatial voids, such as their mutual interaction and their connectivity through the internal circulation of the building. This sub-step is grounded on the application of two specific operations, namely composition and organization. Composition is defined as “the establishment of formal relationships between the elements of architecture”, whereas organization, a complementary concept, is the “formation of relationships between the functional, circulatory and spatial elements of architecture” [9]. In line with the design approach of Koolhaas, the here generated topology is the result of a process of “creating programmatic, cinematographic or spatial sequences” [7]. According to the defined topology, the spatial voids are distributed into the solid mass and their geometry is then adapted to respond to the constraints given by the solid mass itself. Taking advantage of the use of parametric tools, several different articulations of the spatial voids can be explored according to diverse compositional and organizational criteria.

**Boolean Subtraction and Production of the Stereotomic Model**

Through the Boolean subtraction of the spatial voids from the initial solid mass (Fig. 2C) the *stereotomic model* (SM) is obtained (Fig. 2D) in the form of a three-dimensional poché. This is, in fact, the first formalization of the architectural concept, what Eisenman calls the *generic form*, which is defined by properties such as volume, mass and movement [3]. Furthermore, this generic form also complies with the initial specific programmatic requirements and responds to the requested spatial qualities.
Step 2: Evaluation of the Static Stability

Given the positive weight $R_m$ related to the initial solid mass and the negative weights $R_i$ of the spatial voids, the weight of the stereotomic model resulting from the Boolean subtraction is represented by the resultant force $R_{SM}$ obtained by the vectorial addition of $R_m$ and the $R_i$ (Fig. 2C). As the organization of the spatial voids results in a specific distribution of matter within the stereotomic model, the force $R_{SM}$ depends directly on the particular articulation of the spatial voids. That is, different distributions of the spatial voids within the solid mass produce changes in the point of application of the force $R_{SM}$. Therefore, the global equilibrium of the stereotomic model has to be evaluated in relation to its support conditions after every reorganization of the spatial voids.

Given the points $S_i$ representing the location of the supports of the stereotomic model, in order to fulfill the global static stability, the line of action of the force $R_{SM}$ must intersect the footprint $A$ of the stereotomic model, defined by the convex hull of the points $S_i$. In fact, in case this condition is not met and assuming that the supports can just take compression forces, the stereotomic model would be subjected to static overturn. To avoid this, the spatial voids have to be re-arranged until the line of action of the force $R_{SM}$ intersect the footprint $A$.

As a result, due to the mutual dependency between the distribution of the spatial voids within the solid mass and the static stability of the stereotomic model, a dialog between spatial and structural parameters is established starting from the early stages of the design process.

Step 3: Hierarchical Iteration

The stereotomic model previously generated introduces a radical dichotomy between solid and void, producing a three-dimensional poché. In the proposed method, this poché is not regarded as a passive instance in the design process but as the basis for further design iterations to explore new spatial and structural configurations. Hence, additional secondary spatial voids hierarchically depending from the ones previously generated, such as the servant spaces defined by Louis I. Kahn [1] (spaces containing for example circulation elements and installations) can be incorporated in the poché. This results, in turn, in the introduction of hierarchical porosity in the stereotomic model.

The production of these hierarchies of spatial voids within the stereotomic model increases the complexity of the spatial configuration, eventually generating a lighter and more porous structure. In this step of hierarchical iteration, the stereotomic model defined in the previous steps is taken as the new solid mass (Fig. 3A). Additional secondary spatial voids are introduced that activate spatially and structurally the new solid mass (Fig. 3B). After the Boolean subtraction operation is applied (Fig. 3C), a new stereotomic model is generated (Fig. 3D) characterized by different spatial qualities in comparison to the previous one. At the same time, the incorporation of new spatial voids within the solid mass changes the magnitude and the point of application of the force $R_{SM}$ and the static stability of the stereotomic model has to be re-evaluated (Fig. 3C).

Although the given example is generated in only two iterations, the design operations can be iterated multiple times, as long as the sought spatial qualities and the structural stability of the stereotomic model are still fulfilled.
CONCLUSION

The method for the generation of stereotomic models in architecture introduced in this paper constitutes an attempt in the search for contemporary design approaches that integrate spatial and structural parameters from the early stages of the design process. Furthermore, it facilitates the exploration of design variations working in a full three-dimensional design environment. Although based on an algorithmic approach, the design method requires the continuous involvement of the architect to overlook the interaction between spatial and structural parameters and take conscious design decisions.

The design method has been tested by architecture students within the framework of the Master Course “Experimental Explorations on Space and Structure” at ETH Zurich (Fig. 4). The application of the design method in this academic context has shown the potentials of using the stereotomic approach in the conceptual phase of the architectural design process. Nevertheless, this experience has also raised some open questions that will be addressed in further developments of the research. Specifically, due to the repeated iteration of the design operations and the increment in number of spatial voids, occasionally the generated model might reach a level of complexity that cannot be easily handled by the designer; in this regard, a more robust way to control the model has to be defined. Furthermore, in its current state the proposed method addresses the conceptual phase of the design only. That is, the method still does not take into account aspects related to construction and fabrication, which are associated to a more advanced phase of the design process; in relation to this, the influence on the design process of material properties and construction constraints have to be addressed in more details.

REFERENCES


Author's index

Abbas, Günsu Merin ....................... 185
Balla-S. Béla, Szilvia ..................... 105
Bertin, Vito .................................. 79
Botzheim, Bálint ............................. 213
Bödő, Gábor .................................. 235
Castellon Gonzalez, Juan José ........... 177
Chang, Tengwen ............................. 163
Chaszar, Andre .............................. 227
D’Acunto, Pierluigi ......................... 177
Datta, Sambit .................................. 163
De Luca, Francesco ......................... 195
De Paris, Sabine .............................. 55
Dino, Ipek Gürsel ............................ 185
Dumitrescu, Delia ............................ 203
Elkady, Shawkat L. ......................... 169
Ezzat, Mohammed .......................... 111
Fehér, András .................................. 235
Fricker, Pia ..................................... 119
Füzes, Bálint Péter ......................... 73
Gidófalvy, Kitti .............................. 213
Gyulai, Attila .................................. 67
Hadjizianisz, Konsztantinosz ............ 235
Hegyi, Dezső .................................. 73
Heinrich, Benjamin .......................... 243
Iványi, Péter .................................. 221
Kari, Szabolcs ............................... 67
Kikunaga, Patricia Emy ................... 213
Koenig, Reinhard ............................ 15
Kolarevic, Branko ........................... 27
Kulcke, Matthias ............................. 61
Lam, Wai Yin .................................. 79
Lellei, László .................................. 67
Lorenz, Wolfgang E. ....................... 249
Lovas, Réka .................................... 235
Lucchi, Elena ................................. 155
Matsubayashi, Michio ..................... 87
Nováková, Kateřina ......................... 133
Nuno Lacerda Lopes, Carlos ............. 55
Pascucci, Michela ............................ 155
Pletenac, Lidija .............................. 141
Reffat M., Rabee ............................ 169
Reith, András ................................. 213
Riedel, Miklós Márton ..................... 67
Rossado Espinoza, Verónica Paola ...... 127
Sajtos, István .................................. 149
Sárközi, Réka .................................. 221
Schmitt, Gerhard ............................. 15
Seddik, Moamen M. ......................... 169
Selvær, Harald ............................... 99
Sik, András ..................................... 67
Smolik, Andrei ................................ 163
Strommer, László ........................... 49
Sundfør, Ingolf .............................. 99
Surina, Dóra ................................... 235
Szabó, Beatrix ............................... 235
Széll, Attila Béla ............................ 221
Szilvási-Nagy, Márta ...................... 105
Szollár, András ............................... 213
Ther, Tamás ................................... 149
Vári, Barnabás ............................... 235
Watanabe, Shun .............................. 41, 87
Wurzer, Gabriel ............................. 243
Xu, Lei ......................................... 93
Yajima, Kazumi ............................. 33
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"The cadence is perhaps one of the most unusual elements of classical music, an indispensable addition to an orchestra-accompanied concerto that, though ubiquitous, can take a wide variety of forms. By definition, a cadence is a solo that precedes a closing formula, in which the soloist plays a series of personally selected or invented musical phrases, interspersed with previously played themes – in short, a free ground for virtuosic improvisation."