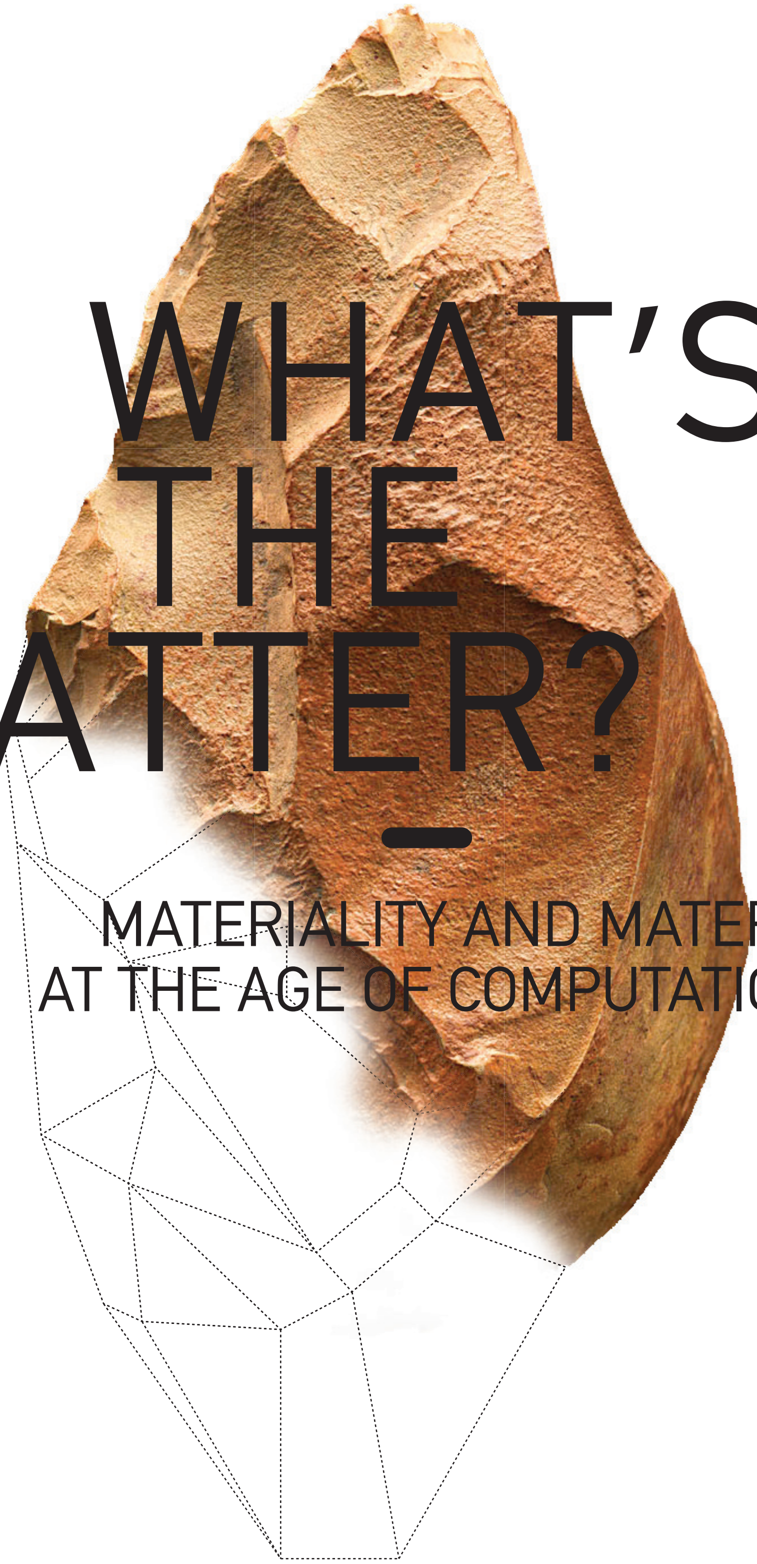
WHAT'S THE MATTER?

MATERIALITY AND MATERIALISM AT THE AGE OF COMPUTATION



EDITOR
MARIA VOYATZAKI

European Network of Heads of Schools of Architecture

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Materiality and Materialism at the Age of Computation

Editor

Maria Voyatzaki

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The Matter of Void: From Absolute Space to Dynamic Flows

Anđela Karabašević

Faculty of Architecture
University of Belgrade,
Serbia

Introduction: Architecture of Air

This paper will address air as a constituent material of space and a primary mediator between human body and the environment. I will propose the notion of *architecture of air* that is not only concerned with rigid matter as a determinant of space but primarily with forms of energy within a given spatial framework, such as heat transfer, air flow, light scattering or electromagnetic fields. The main issue discussed here will be this intangible materiality of space, the invisible aerial processes that significantly influence the perception of built architecture. Whereas Modernity was largely grounded on the Newtonian notion of *absolute space* [1] as an independent aspect of objective reality, the computational era has made us equipped to see the dynamic air that constitutes the environment. Space is no longer considered void nor uniform, but heterogeneous: material and fluid. Accordingly, the design process is being increasingly modified to include the impact of the ephemeral and unstable environment on the architectural object. Most of these changes today are reflected in the final phase of every major project, and involve computational fluid dynamics (CFD) studies of wind and ventilation issues conducted upon an already defined building, usually in order to apply certain mechanical systems and thus resolve any energy losses.

Apart from the issues of energy efficiency, the atmospheric approach raises another important topic - one of subjective perception of space. The aerial phenomena trigger the sensory receptors in our skin, and thus we experience space around us. We feel the air, not the building itself, and it is the air that we should be constructing. However, the elusive nature of these ephemeral, invisible and unstable processes makes them usually difficult to visualize and comprehend. As Mark Wigley (1998) suggests, uncontrolled atmosphere displaces the architect, because it is precisely the atmosphere that the architect is expected to produce. Therefore, practicing architects tend to create an illusion that they have the atmosphere under control. The truth is that it is usually beyond their understanding and left adrift, between carefully constructed form on one side and unstable environment or unpredictable occupant on the other. The emerging architectural theories propose that the construction of atmosphere should be approached as an architectural problem, instead of it being overlooked and dismissed as an engineering issue. However, to design the invisible behaviors, we need new architectural tools for visualization and a new scope of knowledge for understanding and controlling what we manage to see [2].

While this is an ongoing and complex process of prosperity, and we might barely be at its beginning stage, it is becoming perfectly clear that both these tools and the sources of knowledge are already at our disposal. *This paper speculates that the formal expression of a building and its inner aerial processes are inextricably linked*. By designing the geometry of a building, the architect is actually conditioning the air within it. Thus, every architectural object could be studied as an instrument for constructing the atmosphere, its formal expression being a direct result of this process. *In this way, with innovative technology, existing architecture becomes an immense and extensive source of new type of knowledge in terms of air.*

The first part of the paper will briefly review the theoretical arguments that have significantly influenced this hypothesis, outlining the emerging tendencies for a detailed and extensive exploration into the complexity of space and its impact on architectural thinking today. Secondly, I will focus on the human body within such space, discussing the active exchange between the living body and its ephemeral environment. The final part of the paper will test the proposed speculations in the form of an experiment - a CFD simulation conducted upon a traditional 16th century Islamic bath building, in an attempt to unravel the architectural thinking about air and environmental behaviors in the past. The dynamic spatial flows within buildings have been, due to their invisibility, mostly neglected by written histories of architecture (Banham 1984, p. 12). This experiment aims to pose the following questions: (1) what are the hidden aerial processes within ancient architectural spaces?; and (2) how can these processes influence our understanding of architecture today? Drawing on Reyner Banham's book *The architecture of the well-tempered environment*, I will suggest one step further - employing advanced digital tools based on computational fluid dynamics to explore the architecture of the past. The main goal is to illustrate a way to a new methodology of architectural research, one consistent with our own age and its scientific progress, which might lead to reconsidering the materiality of space and the role of air and atmosphere in architecture altogether.

Uniform vs. Differential Towards Heterogeneous Space

In an introductory chapter of an important 2009 book on *heterogeneous space* [3], Christopher Hight, Michael Hensel and Achim Menges point out the lack of architectural theories on complexity of space when compared to progressive explorations of form and program in architecture in the past 40 years. For decades, space has been an 'unthought' problem, a passive result of form-making, or the means for achieving a programmatic order. They write: ''Space has itself become a blind spot within the field of architectural knowledge, one that we cannot see when we look directly upon it but which is increasingly defining the periphery" (Hight, Hensel & Menges 2009, p. 11-12).

Common tools for architectural representation may very well be the leading culprits for this situation - we are taught to represent what we see, and we cannot see the space (at least not with our own eyes). The hegemony of the visual in architecture has made us ignorant of the dynamic character of space - thus we become incompetent to design actual holistic experience of it. In her article ''The Phenomena of the Non-visual," Michelle Addington (2007) writes about *perceptual environments*, stating that what actually determines what we feel is thermodynamic in its nature - it is about the motion of energy, and not rigid spatial boundaries. It is a common phenomenon that the same space never *feels* exactly the same. Even though it might seem homogenous and uniform, its invisible layers, the dynamic flows that mediate the spatial experience, are constantly in flux. Addington discusses the dynamic character of the environment by questioning the meaning of *boundaries* in architecture. Unlike the rigid structure, the relevant boundaries that determine spatial experience are formed around all heat-producing entities in one space (mechanical devices, people), and they are not static nor absolute, but responsive - they signify behaviors and mark energy fields. These boundaries are the enveloping layers of air around the body that mediate the exchange of energy with its surroundings.

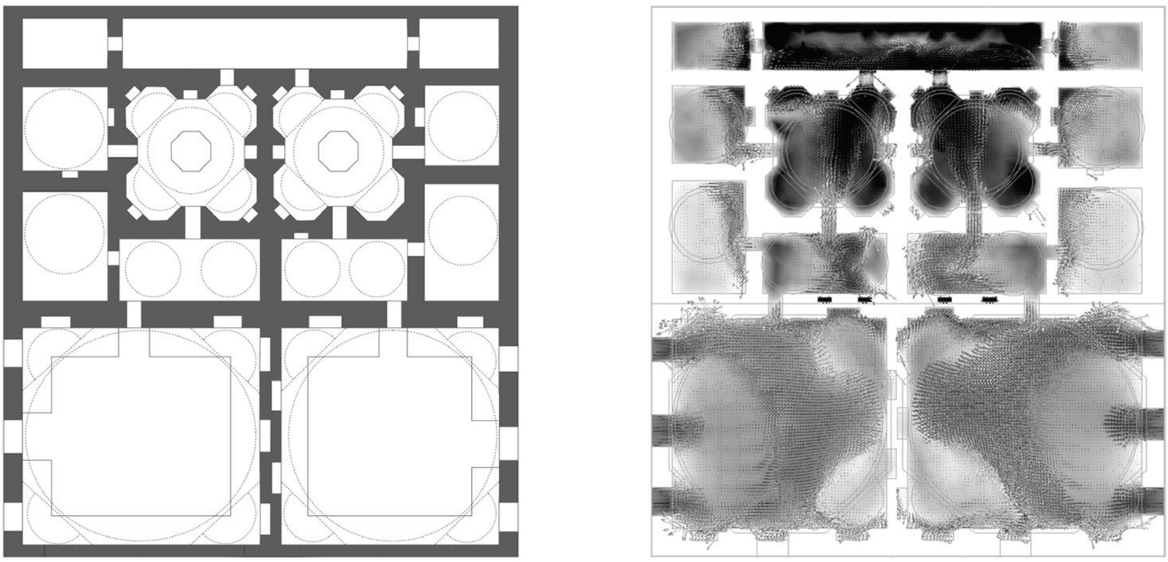

Fig. 1

Two modes of representation: traditional plan drawing and CFD aerial simulation of the same space.

Within the heterogeneous environment, our bodies extend into the space around us, blurring the difference between our own physiology and the physiology of the building. This means that, when moving in space, we are constantly encountering different thermal conditions and actively engaging in a variety of invisible spatial behaviors. The shift in understanding of space as no longer empty, nor uniform, but material and heterogeneous, means that differences are no longer considered deviations from a single uniformity, but as given, existing spatial conditions. Hight, Menges and Hensel write: ''We now understand that the world is constructed through differentials rather than underlying uniformities or models. Everything is produced via events of differentiation, even coherences and order '' (Hight, Hensel & Menges 2009, p. 13). The matter of air that constitutes space is - by its nature - unstable and diffusive, tremulous and spasmodic - this is why it requires so much applied energy to maintain it uniform and steady. ''The air is characterized by turbid swirls, gusts and clusterings, grots, hotspots, pockets and epochs, sudden saltations as well as sluggish dissipations'' (Connor 2004, p.6). It is an endless scope of new materials for architecture to work with. Instead of suppressing it, we should turn this heterogeneity to our advantage.

In the following paragraphs space will be discussed as a thermal field, saturated with information and stimuli that triggers our physiological and psychological response to it. This paper researches into the impact of visible, tangible architectural elements on the intangible, dynamic behaviors of the enclosed air. Both are equally material, in a way that they interact with other entities, and can be registered by the senses. Further development in understanding the connection between architectural form and its inner aerial processes might initiate the formation of a theoretical platform for actual architectural construction of atmosphere.

Thermal Fields and Human Body

There is a significant amount of scientific evidence that people are extremely sensitive to subtle changes in temperature around them. Israeli architect Baruch Givoni (1981) describes experiments that test human sensitivity to still-air temperature using a scale from 0 to 10. He observes that a person can feel the difference not only between various levels, but can also distinguish intermediate levels, ones that he marked as 4.2 (not entirely comfortable, but definitely not slightly warm) or 4.7 (less than slightly warm, but definitely not comfortable). Givoni states that even though thermal experience is individual, every subject develops a consistent and extremely precise thermal scale due to their sophisticated sensory mechanisms that detect external changes (Givoni 1981, p. 50). This implies that in order to maintain one's own responsiveness to environmental stimuli, the enclosed space should be saturated with a range of different temperatures, just like the open air, as opposed to the 'thermal monotony' that the almighty Heating, Ventilation and Cooling systems (HVAC) are designed to establish. In her 1979 book *Thermal Delight in Architecture*, Lisa Heschong writes about thermal sense as an important and independent human receptor, even though it is not included in the traditional list of senses among sight, hearing, taste, smell and touch [4]. It is a known fact that people have nerve endings specialized to detect variations in temperature in different areas of their bodies. These are heat-flow sensors, which means that they mediate and monitor the engagement of our body in the environmental behaviors (Heschong 1979, p. 28). Similar to the five commonly known senses, thermal sense requires stimulation by a variable environment to be activated. Our bodies detect change in our surroundings, and if encountered with a uniform space, they become inert, and lose the ability to adapt to these changes.

In 2005, Steven Connor wrote an invigorating essay on cultural phenomenology of heat, entitled ''Thermotaxis,'' stating that human beings are driven by the changes in temperature around them [5]. ''Our movement is, of course, relative and tactical, thermotactical. To be human is to be a constant regulator of heat: the aim of every human organism is to maintain itself at a constant temperature, not too hot, not too cold'' (Connor 2005, p. 4). This is commonly misunderstood as the need for constant thermal conditions in a living environment. On the contrary, thermal equilibrium is not a state, or a constancy, but rather ''a calculus of fluctuations'' (Connor 2005, p. 5). Thermal comfort is influenced by a variety of factors that determine the gain and loss of heat: air temperature, mean radiant temperature, air speed, relative humidity, as well as metabolic rate, clothing insulation and psychological parameters of an individual. It is a result of a synergy among numerous variable parameters, impossible to precisely calculate and deduce to one single number (the commonly known 21 ˚C). The pursuit of standard temperatures is in contradiction to the very nature of thermoception. Thermal sense detects changes, it asks for actions, not constancies.

Lisa Heschong specifically discusses the feeling of delight, stating that people *enjoy* an abundant range of temperature even though it takes significant bodily effort to adjust to every fluctuation. We often chose extreme thermal environments for our holiday destinations, seeking the stronger stimuli for the ever richer spatial experience (Heschong 1979, p. 32). This might be one of the explanations for the emergence of hot-air and vapor baths, the Ancient Roman *thermae*, Russian *banja*, Finish *sauna* or Islamic *hammam*. The exposure to extreme levels of heat suits the human body, and apart from thorough cleansing, relaxes and calms the soul as well. The chief principle of such places is to induce vigorous perspiration by the application of heat. Increased variations in temperature in different areas of the bath heighten the bodily senses during the bathing ritual, and thus amplify the spatial experience, resulting in intense feeling of delight and vivid awareness of one's environment.

Simulation of Space: The Air of Sokollu Hammam

If we define a building as an instrument for constructing the atmosphere, and air as its crucial element in mediating the constructed spatial experience, the traditional Islamic hammam is one of the most remarkable examples of such hypothesis. Their primary function is to provide amplified sensual experience of space. This is achieved by designing the building as a closed thermodynamic system, where its spatial configuration, air flow, temperature and moisture transfer all work together, in relation to the human body. The main heat source in the hammam is the furnace from which heated air and flames are transmitted via the hypocaust system [6] to the hottest chambers of the bath. The heat and moisture from these chambers are then transferred through space, creating several microclimate zones with a range of gradually changing thermo-hygrometric conditions. The whole bath could be simplified to a double system of voids within brick or stone mass, one conducting hot air and smoke from the furnace, and the other containing different atmospheres for performing the bathing ritual: cold for undressing, warm for relaxing and hot for perspiration and washing.

The following experiment speculates on the correlation between the architectural design and its thermal phenomena throughout the history of architecture. It examines the potential of thermal functions to be used as elements for architectural design. Our main goal is to draw attention to the fact that architecture has always dealt with heterogeneous space, and its formal expression or functional organization are directly linked to its dynamic behaviors. For these purposes, we have chosen a traditional 16th century Islamic hammam in Luleburgasz,Turkey, by a famous Ottoman architect Mimar Sinan [7]. The building was examined in terms of interior atmospheric processes such as air flow and heat transfer in relation to its formal expression and specific human activities it accommodates. The input information taken into account is primarily the original geometry of the hammam, applied materials (mostly brick), the main heat source - the furnace (air temperature of 200˚C) and the average external meteorological conditions for this location (around 25˚C) [8].

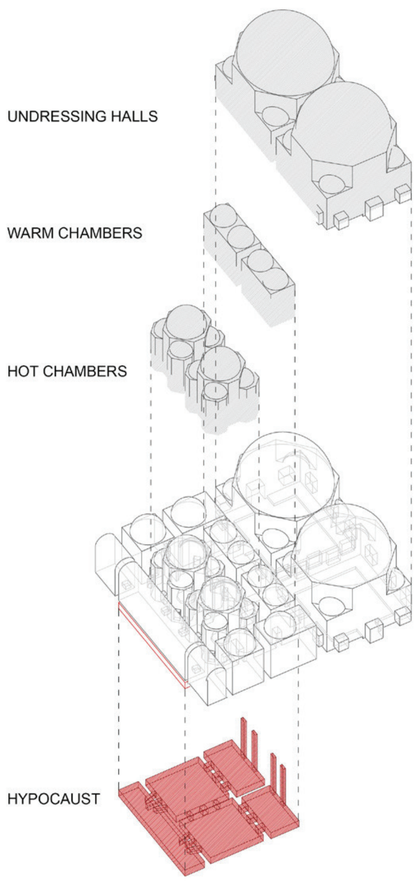

Fig. 2

Sokollu Hammam, Lüleburgaz, Turkey - orthographic view.

Temperature Distribution

Temperature distribution in the hypocaust system (Fig. 3) shows that the air temperature is dropping while it is moving away from the furnace - from underneath the hottest chambers to bellow the warm ones. The reason for this is the division of the whole hypocaust volume into four separate areas, interconnected by narrow channels for hot air and smoke - it allows for the air temperature and velocity magnitude to drop considerably (from 100-180˚C underneath the hot chambers to 60-100˚C underneath the warm ones). The highest degrees are obtained by the wall facing the furnace and in the middle areas of the hypocaust volumes.

Consequently, a particular thermal *airscape* is established inside the bathing chambers above, making rigid boundaries, walls and floors, to dissipate (Fig. 4). The brick mass and the air that it encloses merge into one dynamic system. We can clearly notice the connection between temperature distribution in the hypocaust and the spaces above. The hot air circulates from the heated floor and furnace wall, following the spatial configuration of the building, and forms a range of gradually changing thermal conditions inside the hammam. As our sensory systems activate only in the presence of change, the spatial experience is in this way amplified and controlled by the intentionally constructed variations of temperature. The warmer air in the undressing rooms remains in the upper areas of the space, amidst the domes, following the laws of natural convection [9]. On the other hand, the heated floor in the hot and warm rooms allows for constant circulation of air, establishing the hot air zones at floor area as well as in the domes. The lowest air temperature is obtained in the middle of the room, approximately at head level, as it is the most agreeable treatment for perspiration [10].

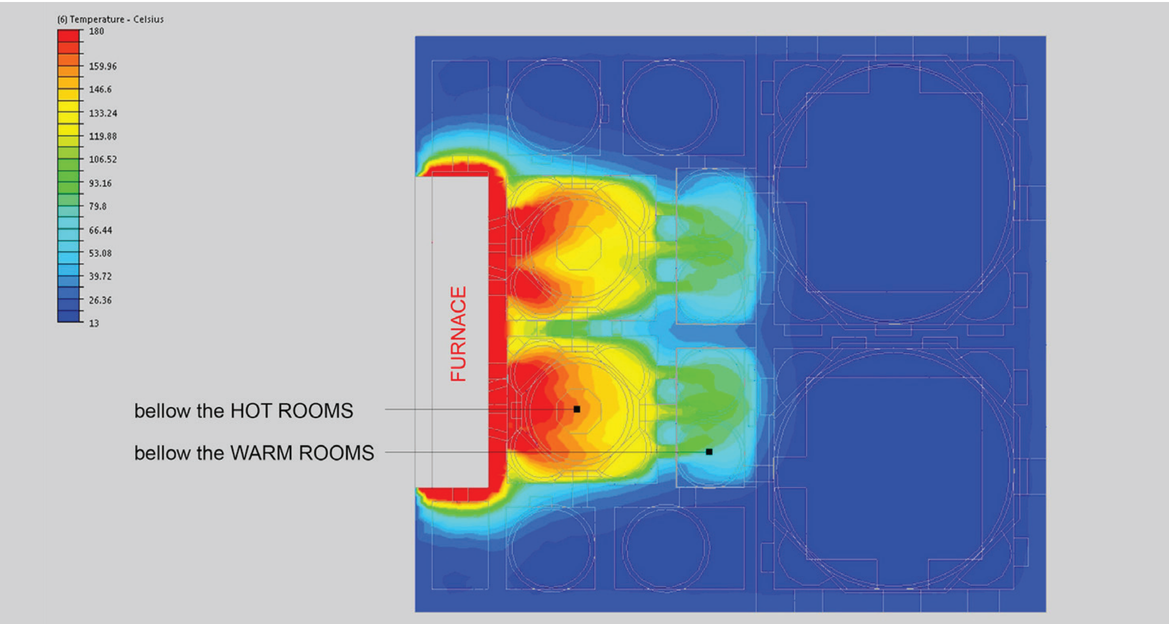

Fig. 3

CFD generated temperature distribution diagram at the hypocaust level of Sokollu Hammam, Lüleburgaz, Turkey.

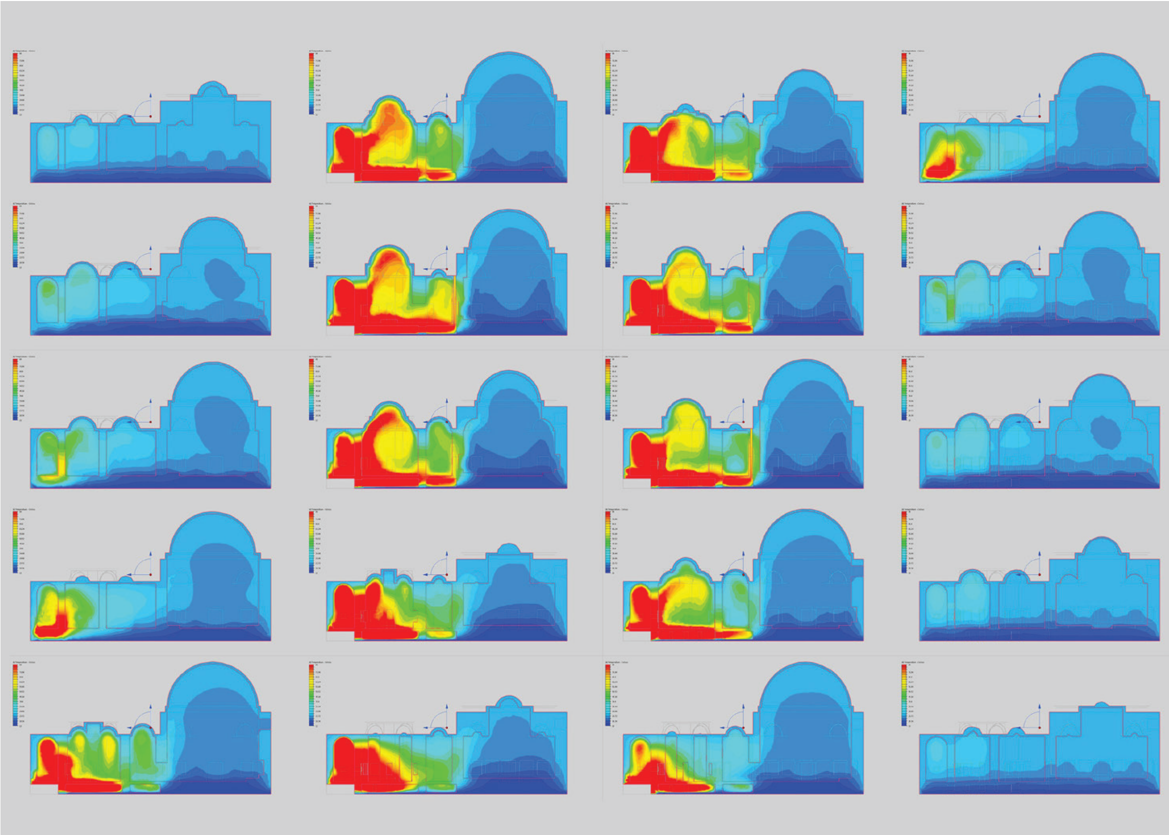

Fig. 4
CFD generated temperature distribution diagrams of Sokollu Hammam, Lüleburgaz, Turkey - a sequence of sections of the building positioned at regular distance.

Air Flow Directions

The air flow diagrams show separately three axial components of air movement in the hammam - directions x, y and z (Fig. 5). The extremes - black and white colors, signify air movement (white in one direction, black in the opposite one), and grey zones show air stagnation - blockages of circulation. For example, in the first diagram on the left the black zones in the middle of the plan indicate the dominant air flow from hot rooms on the left towards the colder ones on the right. Note that on the second diagram the air is moving in relation to the entrance doors, due to different external thermal conditions. Additionally, there is almost no air flow in z-direction in the undressing halls, but it is clearly noticeable in the hot chambers facing the furnace. This is due to the natural convection processes - black color shows air going upwards, and white shows air going downwards. The lower three diagrams imply turbulent air movements (in all directions) following the spherical geometry of the domes [11].

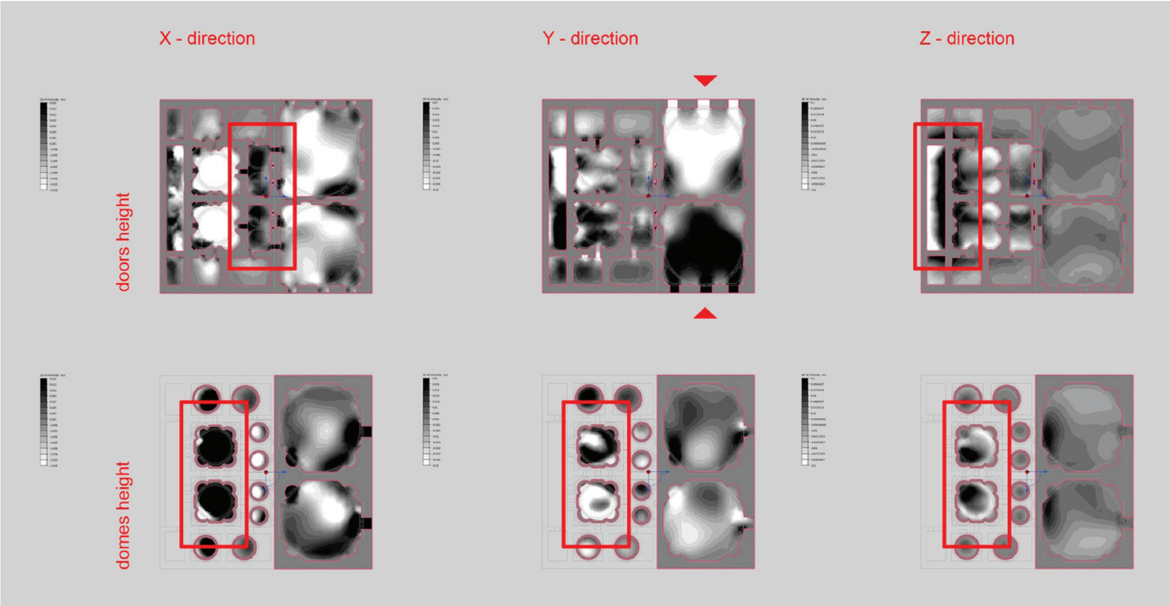

Fig. 5
CFD generated air flow XYZ direction diagrams of Sokollu Hammam, Lüleburgaz, Turkey: doors and domes height.

Air Velocity Magnitudes

The air velocity diagrams show that the highest magnitudes of air-flow are obtained in the hottest zones of the hammam due to the natural convection of air. Also, because of the turbulent air flow in the hot chambers [12], the air in the middle of the room is significantly calmer (Fig. 6). This can be connected to temperature distribution (Fig. 4): colder air is located in the middle of the room. However, this is different in the undressing rooms, as the circulation is connected to the position of the openings - the doors and windows. The moving air is in the center of the room - this is why sitting areas are arranged by the peripheral walls (Fig. 7).

The research process illustrated in this experiment offers a unique way of seeing and representing architecture. It is a scientifically driven methodology to scan the building in order to simulate and document its responsive physiology. Close examination of the 'void' within the hammam is a way to broaden our understanding of this invisible materiality and map the connection between architecture and its air. The hammam is an oustanding example for this, but the same principle could be applied to any type of building. We experience space via its heterogeneity, thus it should be constructed to suit our activities and our own physiology. In this way, architects become trained to observe the aerial behaviors and detect important links between the visible and invisible aspects of their design. Instead of employing computational tools to generate complex geometries, this paper concentrates on another, slightly overlooked use of these tools in architectural research methodologies - actual simulation of space.

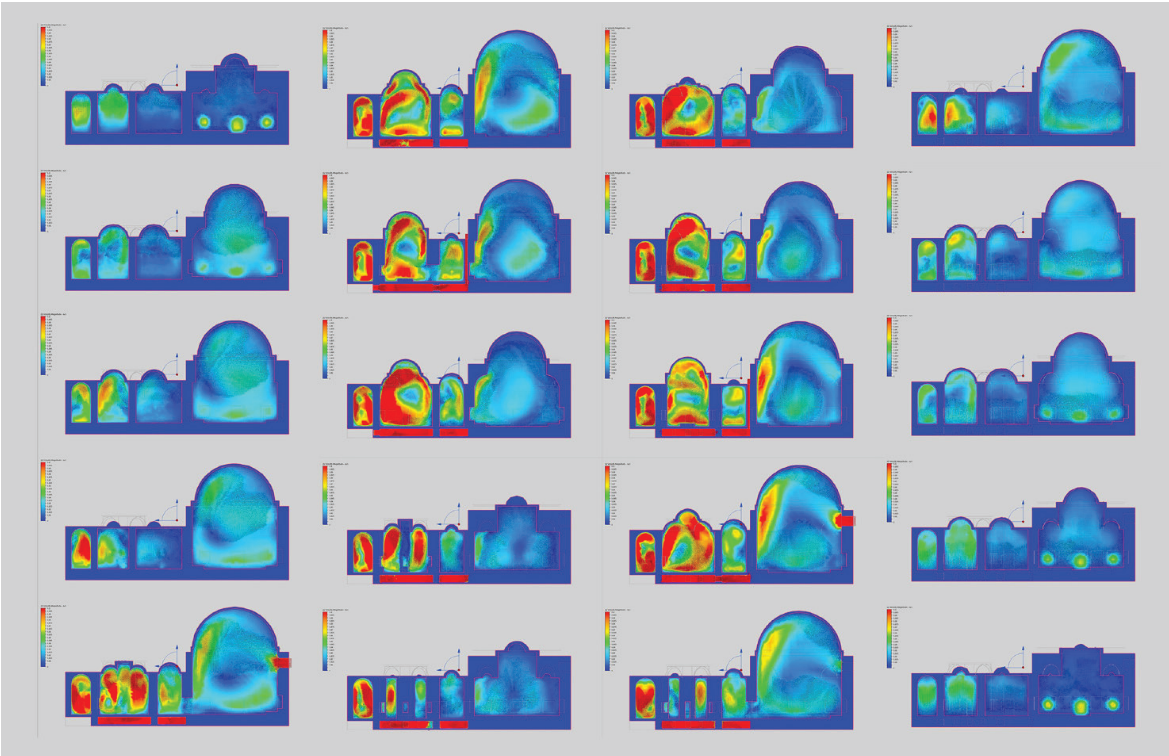

Fig. 6
CFD generated velocity magnitude diagrams of Sokollu Hammam, Lüleburgaz, Turkey: section 1.

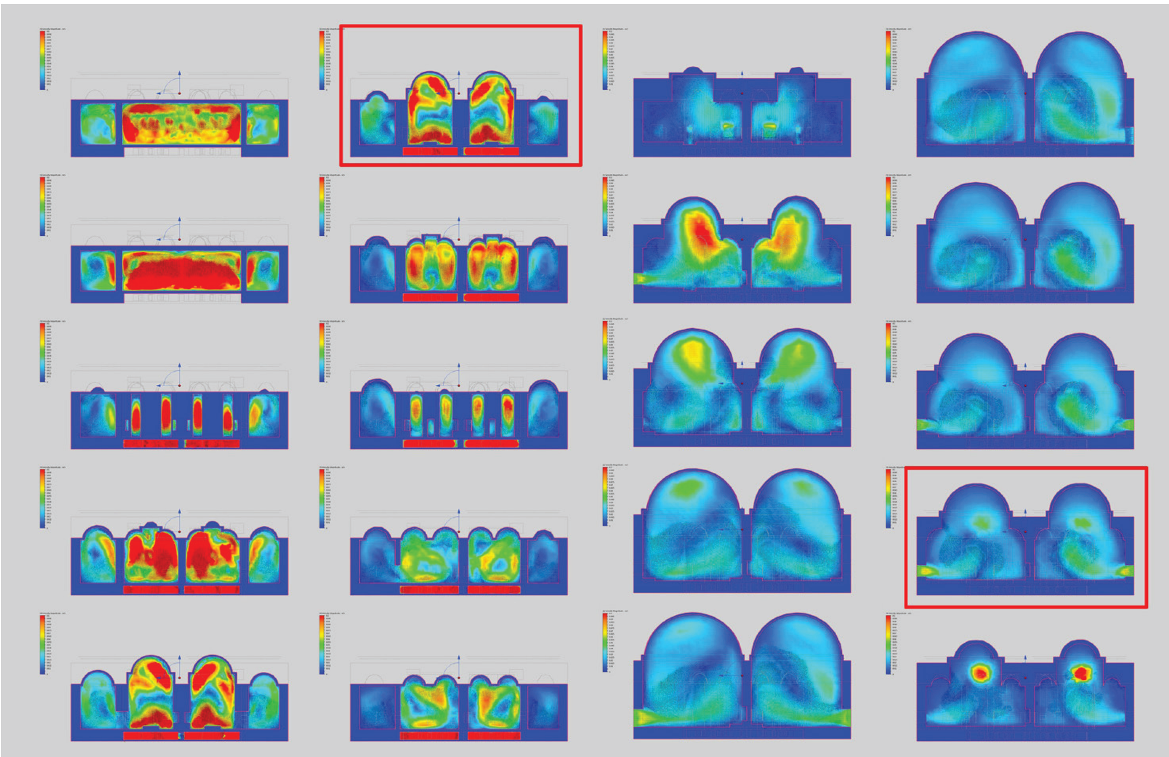

Fig. 7
CFD generated velocity magnitude diagrams of Sokollu Hammam, Lüleburgaz, Turkey: section 2.

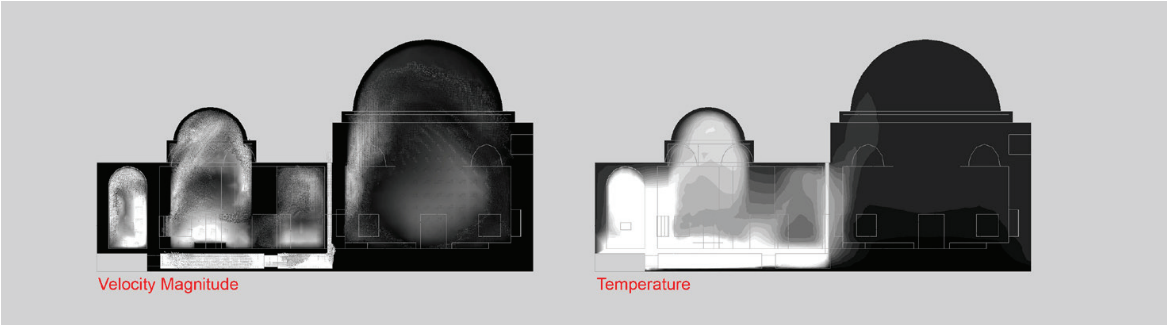

Fig. 8

The air of Sokollu Hammam - dissipation of rigid boundaries (CFD generated diagrams - monochrome).

Concluding Arguments

In his article ''The Poetics of Augmented Space,'' Lev Manovich introduces the notion of *augmented space* as a byproduct of the Informational era: a physical space overlaid with dynamically changing information (Manovich 2002). He is referring to the new layer of physical space, made of invisible data that is carried and transmitted in the air. On the other hand, this paper points to an existing, constituent layer of space, one that has been there all the time, but that was made visible by the innovative computational technologies of today. The complexity of its natural processes and behaviors is only ever more heightened with the supplement of the artificial data flows. Manovich writes: ''Architects should consider the invisible space as substance rather than just a void - it needs a structure, a politics, and poetics'' (Manovich 2002, p. 28).

The obtained results of the experiment reveal the dynamic character of the invisible spatial matter. Rigid boundaries dissipate and merge with the air they enclose, forming thermal *airscapes* within the building. The diagrams clearly illustrate the idea that every single architectural gesture affects these air flows, and thus, significantly alters the 'atmosphere' of the space. It is not a metaphysical hypothesis, it is a scientifically provable fact. Whereas mechanical engineers use mechanization to create a certain atmosphere in a building, they all act upon a given spatial situation, an already defined problem. To a certain extent they do define the atmosphere, but these fixed spatial constraints, they cannot alter. The one who defines the initial spatial configuration, and thus profoundly influences the atmospheric outcome, is an architect. This is why the construction of atmosphere is primarily an architectural issue. However, this particular design method requires substantial knowledge of fluid mechanics, and advanced computer tools for managing these complex processes.

This paper proposes history to be used as a source of a new kind of architectural knowledge. A historical database of architecture in terms of air could be created by examining ancient buildings with advanced digital tools. It leads to connecting historical architecture with technological innovations of today, in order to draw new conclusions about history, and new instructions to employ in contemporary design processes. The computational era has made us equipped to see the dynamic air that constitutes and affects space, to control it, and use it to our advantage. This new power of seeing what our ancestors were unable to see means we can now access their work from a new point of view and approach our own architecture in a new, more comprehensive way. The arising awareness of the materiality of air and heterogeneous space, with technological advances in weather simulations and manipulations could be used to introduce a new way of seeing architecture in terms of air. Spatial processes can now be assigned material qualities and rules of behavior - meaning that they can be designed. In this way the precision of an architect's approach in creating space and habitable environments is significantly improved. *We become competent to understand and precisely construct the experience of space, taking full responsibility for the atmospheres we produce.*

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I would also like to thank my faculty professor Ljiljana Blagojević, for indicating the important link between my theoretical research on architecture of air and the concept of a traditional Islamic hammam.

Images

All presented diagrams were generated by the author of this paper.

Notes

1. This concept was originally introduced by Sir Isaac Newton (1687) in *Philosophiæ Naturalis Principia Mathematica*. According to Newton, absolute time and space do not depend upon physical events. Therefore, Newton's theory assumes that matter has no effect on absolute space, it is completely unaffected by everything that takes place within it.
2. This knowledge is different from common engineering sciences knowledge, as it is related to architectural elements, and not the mechanical appliances used in a building.
3. The authors define the term *heterogeneous* as ''an object or a system that consists of a diverse range of items or qualities, which can include differences in kind as well as differences in degree. These could be multiplicities of things, abrupt changes or smooth gradients" (Hight, Hensel & Menges 2009, p. 12).
4. Steven Connor (2005) states that *thermoception* is among nine senses that are currently identified by psychologists and philosophers of sensation.
5. The term *thermotaxis* denotes '' movement of a living organism in response to changes in temperature," and ''normal regulation or adjustment of body temperature." See: *The Ameri-*

can Heritage Dictionary of the English Language, 2009, 4th Ed., Houghton Mifflin Company, Boston.

6. The elevated floor system originating from the Roman *thermae*.
7. The computer model of Sokollu Hammam was based on technical drawings published in an article on Ottoman baths. See: Büyükdigan, I 2003, 'A critical look at the new functions of Ottoman baths', *Building and Environment*, 38, pp. 617-633.
8. This research focuses on the connection between the geometry of the building and its inner aerial processes. Further analyses might also consider the impact of the variable climatic conditions of the outside environment. However, for this particular case study the external conditions are taken into account only via its average values.
9. Note the dark blue color at floor level in the undressing rooms indicating the lowest air temperature, and pale blue color above, in the domes (temperature difference from 18 to 35˚C).
10. The feet and the rest of the body should be exposed to higher temperatures to induce vigorous perspiration, while the head should remain within lower degrees to maintain the clarity of one's mind.
11. Note the black and white colors with no grey zones in the hot chambers. Also, the opposite colors in the same areas of the hammam, but at different heights indicate swirling air flow.
12. Note the trace of the red color in the hot chambers showing areas of highest magnitudes.

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