The 3rd International Conference with Exhibition
S.ARCH 2016 >>> NEXT ARCHITECTURE
25–27 May 2016, Budva, Montenegro

COMPUTATIONAL ATMOSPHERICS AS A DESIGN TOOL

Anđela Karabašević*

University of Belgrade - Faculty of Architecture
11000, Belgrade, Serbia
*Magnolija 21, 11221, Belgrade, Serbia; andjela.karabasevic@gmail.com

Abstract

The unstable matter of air that constitutes architectural spaces primarily determines our spatial experiences. Buildings are essentially fragile - they emanate energies, vibrate, evaporate into thin air, age and respire. In this paper, I wish to reveal *the potential of advanced digital technologies in exploring the atmospheric dimensions of architecture*, towards its more sensuous, human oriented future. For this purpose, I will introduce the *Museum of Unsettled Air* as a *virtual research platform* for exploring digitally constructed atmospheres, aimed towards better understanding of our immediate reality. In the age after representation, we investigate the intangible architectural rhythms that regulate our experience of the world, bringing us significantly closer to precisely constructing ethereal atmospheric processes in the future.

Keywords

computational simulations, architectural atmospheres, design tool, virtual reality

1 Introduction

"Regardless of their design philosophy, architects try to capture the less tangible effects of a construction, waving their hands around representations of their projects like impassioned spiritualists, drawing invisible lines of force and *predicting the arrival of certain intangible qualities*. [...] Drawings show the edges of buildings glowing or surrounded by a kind of haze that blurs the edges of the object, merging it with the atmosphere." [1]

In 1998 Mark Wigley defined architectural atmosphere as "some kind of sensuous emission of sound, light, heat, smell, and moisture; a swirling climate of intangible effects *generated by a stationary object* ... *To enter a project is to enter an atmosphere*". The unstable aerial phenomena within the building trigger the sensory receptors in our skin, and we experience space around us. We feel the air - the ephemeral effects of light, sound, heat and odors, that are carried on or in the air - even before we visually grasp the building as a whole. Atmosphere seems to be a significant and an inevitable product of the architectural design process. However, the elusive nature of atmospheric behaviors makes them usually difficult to visualize, comprehend and control. More than often, architectural atmosphere is left adrift, between carefully constructed form on one side and unstable environment or unpredictable occupant on the other. The issues of airflow, light scattering, heat transfer or sound propagation are assigned to experts in other engineering disciplines, whereas the holistic effect of these behaviors is rarely analyzed in the conceptual phase of the design process. As Wigley suggests, uncontrolled atmosphere displaces the architect, because it is precisely the atmosphere that the architect is expected to produce. This is why architects tend to create illusions that they have atmosphere under control, by adding a range of mesmerizing effects on representations of their projects, although one might easily call in question each of these seductive architectural elements at any time. Photoshop effects create a spectacle around a building, but do they really speak *about* the space, or merely *for* it? It seems that accuracy gets lost when facing the perplexity of the contemporary digital world.

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. The age of advanced computation has enabled us to process large amounts of data and simulate real life processes, which has significantly influenced scientific investigations of complex behaviors, in physics, biology, climatology etc. Whereas computational models are being excessively used for a variety of important analysis of building's performance, such as structural stability, airflow, heat transfer and daylight analysis, architectural visualization techniques are mostly perceived as market driven tools to show the client what the building will look like before he spends the money to build it [2]. Computerized architectural visualization largely remains in the field of representation. However, advanced software packages, such as 3dsMax and V-Ray, based on the logic of real-life phenomena, go far beyond the visual. These tools are capable to precisely simulate any hypothetical real-life situation, and thus enable architects to understand the physics of invisible spatial processes, such as light scattering, vapor dispersion or material behavior at micro-scale level [3]. This means that, instead of regarding architectural atmosphere as metaphysical and obscure, architectural discipline is now equipped to pursue the *science of atmosphere*, where an architect actually understands "the swirling climate of intangible effects" generated by his building and is able to experiment with it. What once might have emerged as a purely *market driven* tool, has now become an invaluable *design and research* tool, one that brings architects significantly closer to their projects in the early stages of the creative process. In this paper, I will argue that, just like airflow or structural performance, architectural atmosphere can also be simulated, evaluated and designed.

This novel scientific perspective has the potential to significantly improve, if not even transform, the traditional design process. That being said, I will address the issue of architectural visualization - not as a representational technique, but as a design and research tool, one that enables us to investigate and learn about the spaces we create, while we are creating them. Far beyond three-dimensional modeling and production of seductive images, computational atmospherics lead towards understanding the connection between invisible atmospheric phenomena, spatial configuration and applied materials. I will discuss the possibilities of these techniques in relation to the current technological achievements and software development, as well as their impact on the architectural design process, in an attempt to shift the globally accepted view of architectural visualization - from a mere representation of form to a precise simulation of space.

2 Computational Atmospherics

Two decades ago, in 1995, and just two years before Wigley's article on architectural atmospheres, Stan Allen first published his seminal piece *Terminal Velocities: The Computer in the Design Studio*, arguing for the possibilities of the computerized techniques in the practice of architecture [2]. He discusses advantages of rapid prototyping, computer milling and the introduction of difference in the construction process itself, as some of the new ways for architecture to manage the complexity of the real world. Interestingly, he briefly argues against visualization tools, introducing them as market driven and "concerned exclusively with what things look like". Allen further writes that these techniques:

"can only innovate at the level of form. Time, event and program cannot be addressed ... And from the standpoint of perception, visualization techniques assume that a very narrow range of perceptual mechanisms come into play in the experience of architecture: a tunnel like camera vision, ignoring the fluidity of the eye and intricacies of peripheral vision - not to mention the rest of the body's senses" [2].

However, what Allen here enlists as disadvantages of visualization techniques, could actually be interpreted as technical aspects that were yet to be developed. Due to constant technological advancements, it seems premature just to dismiss certain tools, before envisioning their possible upgrades in the future. Two decades after Allen's article, virtual reality headset StarVR, for example, features 210-degree field of view (FOV), which is the widest FOV currently in development, extremely close to completely eliminating the tunnel vision effect in the foreseeable future. It uses Fresnel lens technology for greater coverage of the user's peripheral vision, and dual Quad HD screens that bring the total effective resolution to 5K - for highly detailed, lifelike and seamless virtual experience. Additionally, movement tracking is enabled by submillimeter position tracking system combining gyroscopes, magnetometers, and accelerometers [4]. It might be a matter of time before this technology is applied in the practice of architecture, offering holistic sensual experience of any imagined space before it is actually built in reality.

2.1 *Promising* Velocities

Indisputably, the difference between technological achievements of today, and the ones at the time of Allen's article are considerable. When complex highly detailed simulations such as computational atmospherics are considered, one of the most limiting technical factors has always been processing speed. At the beginning of his article Allen gives the example of IBM's chess-playing computer Deep Blue, that analyzed 200 million chess moves per second. In 1997 Deep Blue won a match against the then reigning world champion Gary Kasparov, and it is known to be the first piece of artificial intelligence to achieve such a victory. Today, scientific research in quantum computing envisions computers that will be able to process data and efficiently solve problems that no classical computer would be able to achieve within a reasonable amount of time. Whereas digital electronic computers, based on transistors, require data to be encoded into binary digits - in one of two definite states (0 or 1) - quantum computation uses quantum bits, which can be in superposition of states. This might raise computer technology to unimaginable levels. In December 2015, it was announced that D-Wave 2X quantum computer, acquired by Google and NASA in 2013, had solved an optimization problem within mere seconds, a processing speed that is 100 million times faster than that of a single-core classical computer [5].

However, along with technical performances, processing speed is inextricably linked to algorithmic optimization, which might reduce the amount of data to be processed in relation to a variety of given parameters. In March 2016, almost twenty years after "Deep Blue" beat Kasparov, a computer program called AlphaGo, developed by a London-based company *DeepMind Technologies* (acquired by Google in 2014), won a match against Lee Sedol, one of the top three Go players in the world (ranked nine dan). The remote possibility of a computer program beating human in professional Go was considered to be decades away, since it required a complex intuitive machinery, that was previously thought only possible within human brain, to even have the idea of who is ahead and what the right move is [6]. Even though the rules of Go are considerably simpler than those of chess, both being games of strategy and clear logic, the complexity of Go lies in the multiplicity of conditions and interrelations that arise from a specific game itself - while in chess typologically differentiated objects are moving through a basically homogeneous space, in Go identities and differentiations of actors are being produced during the game, and they are constantly in flux [7]. This makes the prediction of possible moves unachievable at any speed rates available today, which asks for a reliable strategy implemented via sophisticated algorithms, that will be capable to master such time-space sensitive complexities. The victory of AlphaGo from March this year has announced that such strategies are possible, and highly promising.

2.2 Algorithmic Optimization

Computer performance depends on the logic implemented "under the hood" - simulations of complex phenomena and large amounts of data require advanced algorithms that will optimize calculations to gain highly accurate results in relation to currently available and affordable computer technology. One might imagine real life phenomena, such as propagation of light for example, as an advanced game of Go - the board would be three dimensional, significantly larger (from the size of a room to infinite open space), with multicolored pebbles - combination of specific colors would determine the potential of a single pebble to influence the space around it. In reality, this means that each element in space, its geometry, materiality, its relation to other elements and exposure to the environment creates specific conditions within the surrounding atmospheric field. V-Ray rendering engine is based on a number of optimization algorithms that read these conditions, recognize patterns, and deduce best ways to calculate and simulate behaviors, reducing the data to a calculable level without affecting the accuracy or the clarity of atmospheric simulations. This in turn has the potential to inform the design and initiate discussions about architectural atmosphere in the early conceptual phases of the creative process.

Both V-Ray's and AlphaGo's algorithms derive from the *Monte Carlo method*, dating back to the 1940s, which is extensively used in mathematics to solve various problems by generating random numbers in relation to a set of given properties. AlphaGo uses *Monte Carlo tree search* to find moves based on previously gathered knowledge, whereas V-Ray employs *Monte Carlo ray tracing* algorithm, which is one of the most physically accurate 3d rendering methods today. It renders a scene by randomly tracing samples of possible light paths.

Repeated sampling of each pixel eventually causes the average value of the samples to converge on the correct solution of the rendering equation. Whereas AlphaGo simulates a chosen sample of possible moves and evaluates them - only to select *one* with the best foreseeable outcome, in real life processes all of these "moves" happen simultaneously. Numerous rays of light travel from each light source to the objects in the scene, collect information from each point (material features: color, transparency, texture, reflective properties etc.) and disperse into a number of rays that further travel, reflect on other surfaces, collect information, disperse and so on. V-Ray's algorithms are designed to optimize such behaviors - to analyze the scene and chose a calculable number of iterations that mostly affect the outcome, at the same time dismissing the ones that merely take up time and memory space, and are either invisible to the camera, or the information they derive can be predicted in a simpler way.

Brute force GI (previously called Quasi Monte Carlo GI) is a basic algorithm that establishes a fixed number of light rays reflected from each point in the scene after hitting it by an original ray of light - the greater the number of diffusely reflected rays is, the more accurate and detailed the final image will be. It is not adaptive, as it calculates indirect illumination for each pixel, not depending on its complexity, and it spends the same amount of computing resources, both in clearly visible and in the unimportant parts of the scene (with less details). Brute force is employed for simple scenes - a close rendering of one object, that require an evenly detailed image. However, for complex spatial scenes, other optimization algorithms are applied, since they save processing time significantly. Irradiance Map is an adaptive algorithm that identifies most important areas of the scene, calculates indirect illumination there, and fills the information about the omitted areas by interpolating the data from already computed ones. It essentially builds a three-dimensional map of indirect illumination data points, in relation to the scene parameters and the position of the camera (Fig. 1). IM uses the concept of undersampling to detect the important areas of the scene - at first the entire scene is calculated in the lowest resolution by a non-adaptive algorithm (like Brute force). The most important areas are determined from the obtained data according to several parameters, and these areas are then rendered in higher resolution. This procedure is repeated several times, each time obtaining more data and increasing the resolution. IM parameters that define the important areas of the scene for further calculation include sensitivity threshold to color changes, the scene's geometry, and the distances between neighbouring objects. This leads IM algorithm to detect angles, rounded surfaces, color and material changes and closely positioned objects as areas that need precise indirect lighting calculation. The rest of the scene - flat surfaces and uniform materials - are then calculated by interpolating previously obtained information. Algorithms like IM, that respond to individually set spatial conditions lead to accurate, space-specific atmospheric simulations, that in turn result with highly detailed spatial data to inform the design process.

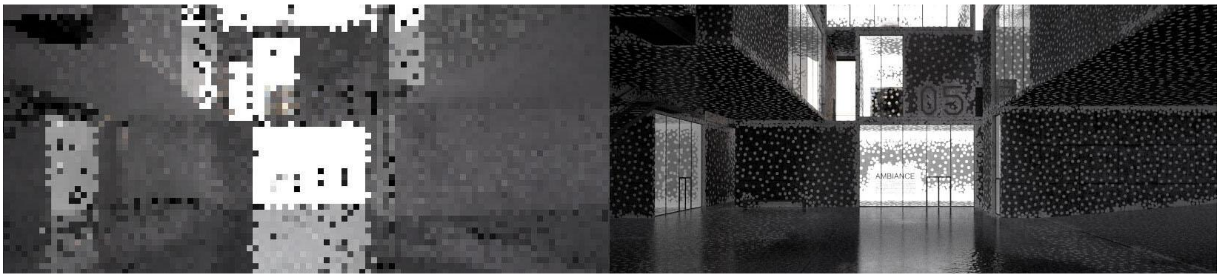

Figure 1: MUA - IM sampling - Important areas gradually gain more samples

2.3 Spatial Tuning and "Atmospheric Intuition"

Architectural visualization software packages are developed to simulate real life phenomena accurately and efficiently, which corresponds to time-pressing demands of architectural workflow and essentially makes precise atmospheric simulations feasible during the design process. This approach requires new type of architectural knowledge and advanced technical expertise, most efficiently gained in practice and via virtual research platforms. *Museum of Unsettled Air* (MUA) is a digital experimental setting for atmospheric research, initiated within *AKVS architectural practice*, aimed towards better understanding of our immediate reality [8]. We observe, analyze and simulate real life atmospheric phenomena and its interactions with the material world, each time drawing invaluable conclusions that in turn inform our own ongoing projects. Rendering engines are defined by numerous parameters that direct and optimize atmospheric simulations, and each individually performed simulation brings us closer to understanding the connections between spatial configuration, material behavior and environmental conditions, thus obtaining invaluable tacit knowledge and developing our own "atmospheric intuition".

It is a common myth among the 3d visualization beginners that there is a specific set of parameter values that will render a perfectly realistic image, but that these settings are carefully hidden from them by professionals in the field. Interestingly, this view is in contrast with the basic logic of V-Ray: every parameter is inextricably linked to the specific space and the atmosphere of the scene, which means that perfect hyper-realistic renderings go hand in hand with thorough understanding of the architectural space in question. Most prominent visualization artists today, Peter Guthrie, Henry Goss or Bertrand Benoit, are architects or architectural photographers, they think spatially, not graphically. Even though advanced software packages are equipped with state of the art algorithms for optimization of the rendering process, it ultimately comes down to manual tuning of the scene geometry, materials, environment settings and rendering parameters, always in relation to the space and its atmosphere. That being said, it seems utterly illogical to separate 3d visualization process from architectural design, and to regard it simply as a technique for representing the final idea.

Computational simulations of atmospheres broaden the design process to a variety of new perspectives. Architecture is created in relation to a specter of different environmental conditions it will encounter in real life. In this way, each material, along with its technical specifications (density, hardness, thermal conductivity, tensile strength etc.), is attributed with its specific *atmospheric performance* - behavior in different weather conditions, texture and structural imperfections, color variations, and so on. All of these properties can be digitally programmed and simulated within the architectural space, making them an integral part of the design process. Lighting can be tuned in a similar way, by adjusting the position and types of light sources, light temperature and color, its intensity etc. Realistic computational lighting needs to consider that human eye constantly adjusts to the broad dynamic changes in our environment (what Allen calls "fluidity of the eye"), so we see in a wide scope of varying light conditions. This is achieved by high-dynamic-range images (HDRI) that store and reproduce greater dynamic range of luminosity than it is possible with standard digital imaging (Fig. 2). HDR images literally illuminate the virtual space with a spectrum of intangible information extracted from real life environments.

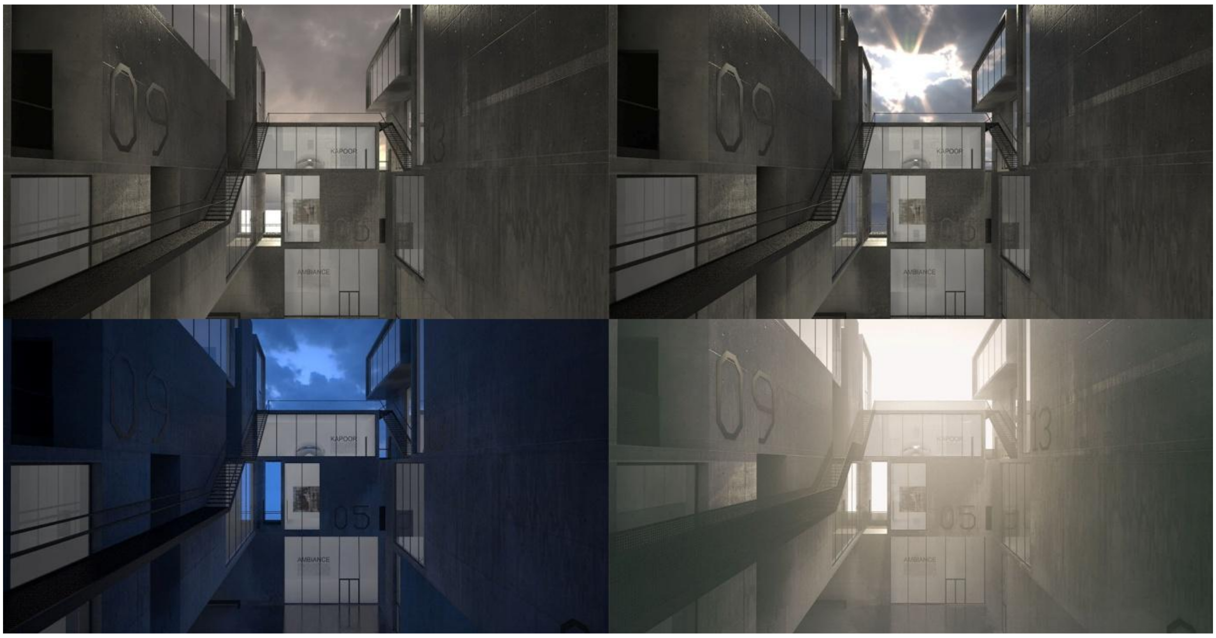

Figure 2: MUA - HDRI lighting tests: (1) gloomy, (2) clearing sky, (3) dusk, (4) fog

Computational atmospherics generate digital fields of data about a building and its environmental behavior that provoke new ways of perceiving and understanding architectural space. Generated images can be differentiated in a variety of separate render elements, each carrying a specific type of calculated information - such as color, direct and indirect illumination, shadows, reflections etc. (Fig 3) Introducing a range of atmospheric elements into the design process generates novel types of spatial properties and greatly supports various design decisions. For example, simulations of rain lead to differentiating spaces according to rain exposure, surfaces according to their inclining angle, materials according to the temporary and permanent traces of rain and their patterns and so on (Fig. 4). Intangible atmospheric behaviors become integral part of the creative process, and the whole building is designed as a complex mechanism that responds to the unsettled air of its environment. In this way, architects are able to understand the ethereal spatial processes and to work with them, which significantly strengthens the connection between architecture and its surroundings.

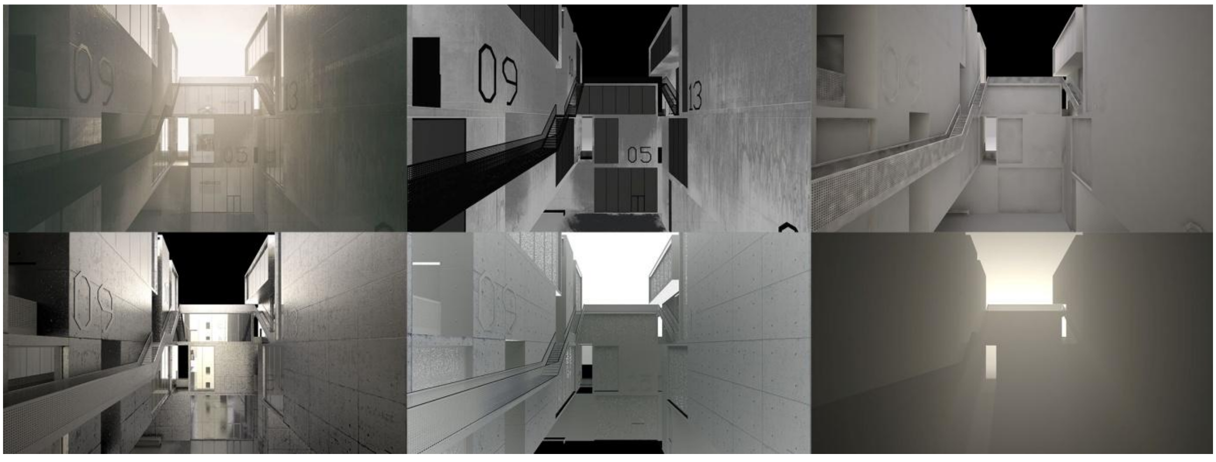

Figure 3: MUA - simulation of fog (density 80m), render elements: (1) superposition of elements, (2) color, (3) global illumination, (4) reflection, (5) shadows, (6) atmosphere

Figure 4: MUA - simulation of rain (animation frames)

3 Concluding remarks

Narrowing architectural visualization to production of seductive images that copy reality would be diminishing it of its much wider potential within architectural design practice. Robert Kosara distinguishes two types of informational visualization - (1) pragmatic, very technical, analysis oriented work done in computer sciences, and (2) artistic visualization without much technical knowledge, much like architectural visualization is commonly perceived today [9]. In an attempt to define visualization more precisely, Kosara writes:

"It is based on (non-visual) data. A visualization’s purpose is the communication of data. That means that the data must come from something that is abstract or at least not immediately visible (like the inside of the human body). This rules out photography and image processing. Visualization transforms from the invisible to the visible." [10]

In architectural visualization, the word *visualization* refers to the *communication of processed data* - layers of information, resulted from computerized simulations of highly complex real life processes, enrich and direct the design process. Rendered images are research products, data visualization media, and they are constantly being updated in pursuit for a specific spatial experience. In this way, intangible atmospheric behaviors become constituent elements of architectural spaces, which brings the design process to a whole new, more humane level.

Technological advancements announce new ground-breaking achievements in the fields of computing, artificial intelligence and virtual reality. Graphic processing units (GPU) promise greater speeds with affordable equipment, meaning that atmospheric simulations will be possible in real time - spatial tuning and atmospheric testing will soon be a matter of minutes or even seconds, which promises even greater design possibilities. VR advancements indicate that, just like today one can simulate realistic lighting and material behavior within architectural space, it might soon be possible to set specific temperatures, odors or sound properties, and automatically simulate and experience space in one holistic virtual setting. The arguments presented in this paper are meant to broaden the field of possible applications of architectural visualization in the design process. As I have tried to illustrate, "time, event and program" can be addressed via computational atmospherics and spatial moods can be precisely constructed and implemented in the conceptual design of buildings. Instead of narrowing architectural design down to representational and market driven aspects, visualization tools have the potential to do quite the reverse, and to direct us towards a more sensual and human oriented future, one with increased responsibility over the spaces and the environments we create as architects.

Acknowledgements

The author of this paper is supported by the PhD student scholarship of the Ministry of Education, Science and Technological Development of the Republic of Serbia. This paper is a result of research conducted within AKVS architectural studio. I would like to thank my colleague Vladislav Sudžum for his timely advice, and for all the inspiring discussions on the subject.

References

[1] Wigley, Mark, The Architecture of Atmosphere, *Daidalos*, 68, (1998), pp. 18-27

[2] Allen, Stan, Terminal Velocities: The Computer in the Design Studio, in *Practice : Architecture, Technique and Representation*, (Allen, Stan), Taylor & Francis Ltd, London, United Kingdom, 2009, pp. 70-93

[3] Karabašević, Anđela, Architectural Atmospheres in the Age of Computational Simulations: The Case of Pre-Constructed Space, *Proceedings*, STRAND, Going Digital: Innovations in Contemporary Life, Belgrade, Serbia, 2015, 113-124

[4] Oscillada, John Marco, *List of All Virtual Reality Headsets Under Development*, http://www.virtualrealitytimes.com/2015/03/19/list-of-all-virtual-reality-headsets-under-development/, published March 19, 2015, accessed April 1st 2016

[5] Neven, Hartmut, *When can Quantum Annealing win?*, http://googleresearch.blogspot.rs/2015/12/when-can-quantum-annealing-win.html, published December 8, 2015, accessed April 1st 2016

[6] Koch, Christof, *How the Computer beat the Go Master*, http://www.scientificamerican.com/article/how-the-computer-beat-the-go-master/, published March 19, 2016, accessed April 1st 2016

[7] Hight, Christopher, Hensel, Michael, Menges, Achim, En route: Towards a Discourse on Heterogeneous Space beyond Modernist Space-Time and Post-Modernist Social Geography, in *Space Reader: Heterogeneous Space in Architecture*, (Hensel, Michael, Hight, Christopher, Menges, Achim), Wiley, Chichester, United Kingdom, 2009, pp. 9-38

[8] AKVS architecture, *Museum of Unsettled Air*, http://www.ak-vs.com/research/res_04_unsettled.html, published December, 2015, accessed April 1st 2016

[9] Kosara, Robert, Visualization Criticism - The Missing Link Between Information Visualization and Art, *Proceedings of the 11th International Conference on Information Visualization (IV)*, 2007, pp. 631-636

[10] Kosara, Robert, *What is Visualization? A Definition*, https://eagereyes.org/criticism/definition-of-visualization, published July 24, 2008, accessed April 1st 2016