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The multidimensional model - an educational and creative tool for designing sustainable reconstructions of urban structures

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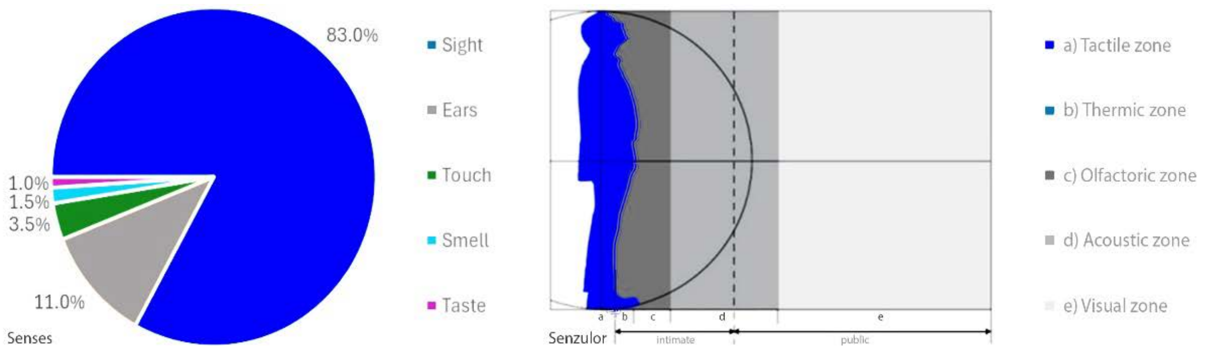
ABSTRACT: The authors explore multidimensional models as a combination of physical maquettes with mixed reality technology within architectural education and practice, emphasising a shift from conventional teaching methods. They suggest that incorporating sensory-rich presentations can deepen understanding of urban and architectural problems. Despite ambiguity surrounding their definitions and methodologies, multidimensional models possess untapped potential that justifies their integration into pedagogy and participatory planning. The article provides methodological instructions for production, emphasising the importance of interdisciplinary collaboration. The principle of co-operation is a synergistic element in a comprehensively organised design process and a key educational element. Selected case studies, including projects in Bratislava, Slovakia, and Accumoli, Italy, demonstrate the efficacy of multidimensional models in fostering discussions on urban development and facilitating sustainable reconstruction efforts post-disaster. These interactive tools serve students, professionals and public to envision lost heritage and sustainable futures of urban structures.

INTRODUCTION

At the heart of architecture lies the art of representation - a process distinct from the physical act of construction. Architects, in essence, are creators of representations rather than buildings themselves. Throughout history, from 2D drawings to physical and digital models, the challenge has been to articulate designs in a manner that is both illustrative and legible. However, contemporary tools present limitations, such as the scale constraints of physical models and their inability to display processes in time, the flatness of traditional drawings and the isolation of virtual reality headsets. To address these challenges, the fusion of physical models and mixed reality technology emerges as a promising solution. By combining the tactile experience of physical models with the immersive capabilities of mixed reality, this visually appealing spatial tool has the potential to engage the public more effectively, leading to a more participatory approach to design.

THEORETICAL SCOPE

The didactic theory confirms that the senses are portals of information. All people learn through hearing, seeing or doing, but everyone has their own unique preference for learning. The use of senses and their combination is typical for mixing learning styles [1]. People receive a different percentage of information with each sense and remember it differently. It is necessary to distinguish between receiving and remembering information. People receive the most information visually, whereas through hearing it is considerably less (Figure 1a). However, the amount of remembered information vary - one remembers only 30% of what one sees visually and 20% of what one hears, but 90% of what one actively does [2].



a) b)

Figure 1: a) graph of sensory reception (by the authors); and b) based on a drawing and theory of *Sensulor* by Keppl and Špaček from 1986 as a parallel to *Modulor* [3] (by the authors).

Mixed reality also actively uses the first two senses with which one receives the most information, i.e. sight and hearing. The kinaesthetic style of learning is based on activity and engages all (other) senses without preference. It is proven that the most effective learning method is the combination of learning styles. Thus, a person remembers up to 80-90% of what he/she hears, sees and does at once.

The *Sensulor* image (Figure 1b) shows the range of the senses. At the same time, it shows the radius of information that people are able to receive in a given sense. Although the eyes capture most of the information, at the same time people are saturated with visual information, so it is possible to use the method of inverse involvement of the senses. These combinations of sensory perception affect the overall impression, feeling or state of a person in various situations [3]. These phenomena are manifested positively or negatively mainly in the perception of architecture. Therefore, it is important to pay attention to them in the preparation of multisensory architectural presentations intended for the public [4], utilising a combination of visual stimuli and tactile inputs by physical models.

In the European context, several cities utilise physical models together with visual information to present future development projects, intentions and municipal visions. Examples include urban models in Hamburg [5] and Berlin [6], serving as effective communication tools in large urban areas. Following Germany's reunification, Berlin's historical centre became the focal point of planning and construction activities. In this context, the first Berlin 3D model emerged as a fundamental tool for discussing planned construction projects, evolving into a pivotal planning instrument and later serving as a contextual model for numerous urban and architectural competitions. The city of Berlin currently possesses four models in scales ranging from 1:1000 to 1:500, mapping extensive downtown development since 1990 [6]. Hamburg similarly recognised the need for a 3D city model, with detailed models of the Hafen City and other urban areas serving as vital tools for urban transformations and enhancing education efforts for students and the public [5].

These physical models serve as invaluable educational tools for aspiring architects and urban planners. Additionally, architectural models play a crucial role in the early stages of architectural education [7]. These models serve as tangible representations of architectural principles and design concepts, allowing students to grasp fundamental concepts, such as scale, proportion and spatial relationships [8]. Furthermore, physical models are instrumental in the education of architectural history, providing students with a visual and tactile understanding of historical architectural styles, techniques and cultural contexts [9]. By studying historical architectural models, students gain insights into the evolution of architectural design and develop a deeper appreciation for the rich architectural heritage.

However, the mentioned examples did not combine physical and virtual components. A step towards this integration is evident in London's physical model with interactive projection [10], which showcases the city's historical development through sophisticated projection systems covering over 85 square kilometres of London. Additionally, touchscreens provide detailed information on buildings and infrastructure projects, revealing proposed developments across the capital. Similar solutions are emerging elsewhere, such as the model recently introduced in the Ethnographic Museum in Budapest, Hungary, presenting supplementary multilingual information to visitors *via* tablets and AR technology (Figure 2).

Figure 2: Multidimensional model viewed through a tablet in the Ethnographic Museum in Budapest, Hungary (photographs by the authors).

Another 3D model utilised in the interactive laboratory MIT Media Lab demonstrates the utility for expert-participatory projects involving integration and finding spaces for immigrants. The model allows for various forms of exploration and evaluation of the city in real-time utilising Lego bricks, algorithms and interactive projection mapping [11].

The potential of combining physical 3D models with virtual layers is evident in the described examples, facilitating a better understanding and evaluation of the volumetric-spatial structure. This potential is far from exhausted. A multidimensional model may also have a physically variable components to a certain extent, allowing for the depiction of various future scenarios and the expansion of the model.

The predominant benefit lies not only in a scientific-artistic understanding and evaluation of issues but also in practical applications in education, pedagogical processes and teaching through a new, interactive form. This approach is exemplified by ongoing efforts in the Faculty of Architecture and Design (FAD) at Slovak University of Technology in Bratislava, Slovakia, to produce a multidimensional model of the central part of Bratislava city in the scale 1:2000, and a model of the Accumoli town in Italy in the scale of 1:1500, involving students in the creation process and enhancing their learning experience.

METHODS

The models were produced in the design studio Data[LAB] in the FAD - a multi-disciplinary educational platform for designers and architects, emphasising a data-driven computational design and an experimental methodology. The research themes of the studio are centred on the understanding of the relationship between virtual and physical spaces. The approach developed for this case named *Space the One* connects physical objects with their virtual counterparts, thereby creating extended realities. This approach is applied across various scales and applications in the studio, from urban planning to product design, and from user experience (UX) design to virtual reality (VR) gaming environments. The main driving force of the studio is the interweaving of virtual and physical spaces, objects and bodies.

Experimental methodologies are employed, which are believed to have the potential to respond to the new social fabric and behaviours brought about by the digital turn in society. These methodologies allow for the exploration and understanding of the implications of digital transformation on various aspects of human life and society.

Multidimensional models are part of the thought process addressing the problem of the digital twin. The traditional approach involves creating an enhanced digital copy of a physical entity. However, a different route is taken in the projects mentioned here. The focus is on overlapping and mixing the virtual and physical domains to create an independent augmented entity. This approach allows for the exploration of new possibilities in the realm of extended realities and offers a fresh perspective on the interaction between the virtual and physical to tackle the problem of architectural models.

Digital layers on the models thus variably display the development scenarios of construction, transport and anti-flood activities, as well as the historical development of the territory. From an artistic point of view, it is possible to verify the silhouette and panorama of the city during the construction of high-rise buildings or night lighting concepts on the models. The connection of the physical model is also possible, which gives basic information about matter and space, with virtual reality, which in turn enables the visualisation of the experience from the human horizon and popularises urban planning and urbanism.

Based on all the mentioned examples, multidimensional models integrate different virtual layer display technology: backlighting, projection, augmented or virtual reality. Each technology has its advantages and disadvantages. Backlit models offer the most impressive experience, but only with flat models, while the backlight display limits the material of at least part of the model to transparent. The model is thus less legible under standard lighting. However, the multidimensional model can be variable in space and time and can combine backlighting, AR projection, VR into one whole, which was also the purpose of this verification study (Figure 3).

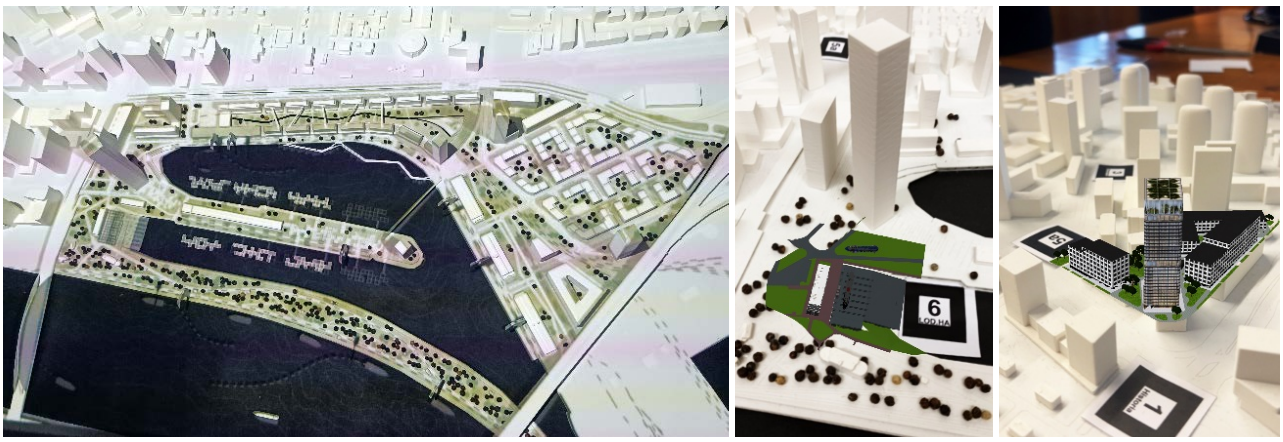


Figure 3: Urban model of Bratislava with a projected layer and 3D augmented reality layers displayed on 2D markers, developed in Data[LAB] (photographs by the authors).

Students, by producing multidimensional architectural models, engage in a *learning by doing* approach, immersing themselves in hands-on experiences to cultivate practical skills and creative problem-solving abilities. Through the integration of digital fabrication technologies, such as laser cutting, CNC machining and 3D printing, students gain proficiency in crafting physical models that represent their design concepts with precision and detail. Working with materials and production machinery educates them to responsibly prepare geometry and assembling produced parts, thereby equipping them with essential skills for their future profession.

Creating such models supports co-operation between students. The task for more experienced students in higher years of architectural education is to develop tools and templates. These resources will assist students in the early stages of their education, providing support for digital fabrication and software applications to empower them to produce their physical and virtual layers for the multidimensional model.

Virtual layers of the model further enhance the learning experience by allowing students to interact with their design concepts with visible contextual data, fostering a deeper understanding and exploration of spatial relationships and design possibilities. Students engage in research on environmental data and sustainable energy sources utilised by the city, learning to create analyses of solar irradiance [12], patterns of shadows and views from specific positions in the city. Through hands-on exploration, students gain insights into the interplay between urban form and environmental factors, developing skills essential for designing sustainable urban environments. By integrating virtual layers into the multidimensional model, students contribute to a comprehensive understanding of the city's dynamics and aid in the development of innovative solutions for future urban challenges.

A multidimensional model is a physical model combined with an interactive virtual presentation. It thus enables interactive spatial creation, verification and presentation in a wider time frame. The digital component of the model bridges different time periods, displaying past state of the urban structure, current situation and planned future developments. It spans various scales, offering detailed insights into urban, architectural and interior design aspects. Virtual reality tools provide visualisations of interior spaces within certain buildings.

MULTIDIMENSIONAL MODEL OF BRATISLAVA, SLOVAKIA

The aim of the educational projects in the FAD was to create a multidimensional model of the central part of Bratislava city, integrating multiple contextual data layers. These layers include traffic patterns, significant historic buildings, existing building programs, planned developments, green spaces, noise maps, shadow maps, key viewpoints, solar irradiation levels, flood control measures and the historical evolution of the Danube Rivers shape. Displayed through LED screen backlighting, the 3D printed transparent buildings provide valuable design inputs for current and future students' academic projects. The focus of the multidimensional model is to serve as a contextual model for upcoming academic and city projects in collaboration with the Metropolitan Institute of Bratislava.

The current dimensions of the model are 290 x 90 cm. The model is divided into two parts positioned on two LED screens. Covering the city centre with the Bratislava Castle to the north, the River Danube, and the city park of Janko Kráľ to the south, it extends from the Winter Harbor in the east to the Slovak Parliament building in the west. There are plans to expand the model to dimensions of 290 x 270 cm, divided into three parts on three LED screens, to include representation of the main train station to the north as well (Figure 4).

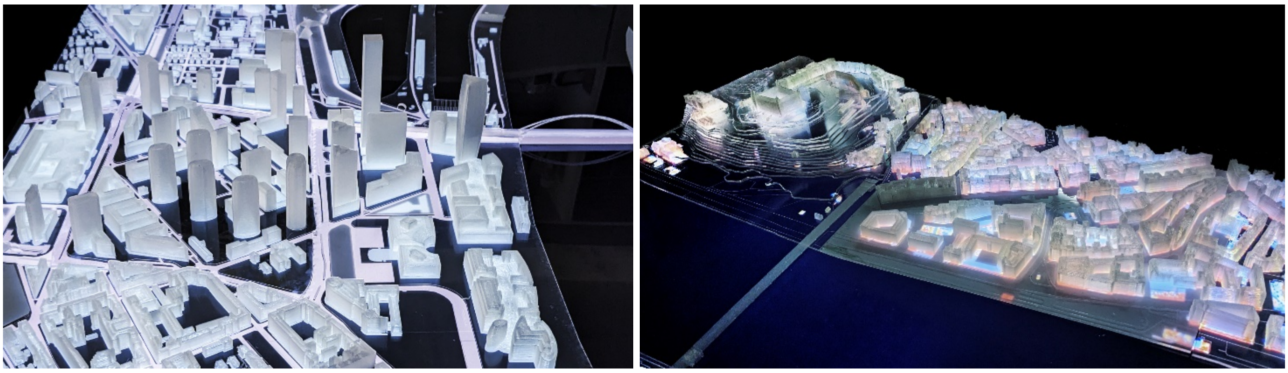


Figure 4: Urban model of the central part of Bratislava showing the historical development of the zone and its possible future scenarios in variable virtual layers, developed in Data[LAB] (photographs by the authors).

The model has been produced over two years mainly by students of the Data[LAB] studio in the FAD including a doctoral student and eight students from the fourth to the sixth year of study. Given the extensive scope of the city represented by the model, co-operation between students was essential. A template and workflow for modelling and 3D printing of buildings specially optimised for backlighting by a LED screen was developed by the doctoral student. The outcomes from the template were printed using four Prusa printers with PLA translucent filament. Bottom bases of the geometry were removed, allowing light to easily pass through. The template is easy to use and it is available for all students for printing their academic projects.

Similarly, students of Data[LAB] in the Master study programme designed a presentation template tailored for backlighting of the model. The template was prepared in the Microsoft PowerPoint, mostly used for presentations in the

FAD. The template includes images in a correct scale and pre-set animations. This user-friendly template allows easy modification of the virtual layers, even by students in their first year of study, facilitating collaborative learning and knowledge sharing across all levels of architectural education.

The prepared templates enabled support for expansion of the model. The digital modelling and 3D printing of buildings were undertaken with the assistance of 154 first-year students enrolled in the course focused on software modelling tools. Building footprints for expansion were sourced from OpenStreetMap and distributed evenly among students through computational methods. Each student gained hands-on experience in digital modelling and 3D printing techniques by preparing masses of 30 city buildings according to exploration in the field.

The semi-finished prototype of the model, along with its digital component, has been already utilised as an interactive contextual model in 14 academic projects. It has been showcased in six midterm and four final reviews, effectively communicating the ideas of these academic projects to juries and professionals. Excluding academic presentations, the multidimensional model of Bratislava was featured at prestigious exhibitions, including the international exhibition Czech and Slovak Architecture at the Bratislava Castle, the K4 exhibition at the Pisztory Palace in Bratislava, the exhibition Augmented Architecture and Night of the Architecture and Design in the FAD. These exhibitions provided platforms to showcase the model to a diverse audience, raising awareness about urban development and shaping the city's image. Beyond its educational value for students, the model serves as a teaching tool for the public and younger generations, fostering a deeper understanding of urban planning principles and encouraging active participation in shaping the future of the city.

MULTIDIMENSIONAL MODEL OF ACCUMOLI, ITALY

The second multidimensional model depicts the town of Accumoli in Italy, which was devastated by an earthquake disaster in 2016. This model showcases the urban structure as it existed before the disaster, serving as an interactive participatory tool for locals and stakeholders to strategise the town's renewal and envision future scenarios. With variable physical representations of the town centre in both its present and pre-disaster states, the model offers a tangible platform for discussion and decision-making. As the town is situated in the highlands, the LED screen backlighting is impractical, strategies for town renewal are instead projected interactively onto the model. (Figure 5).

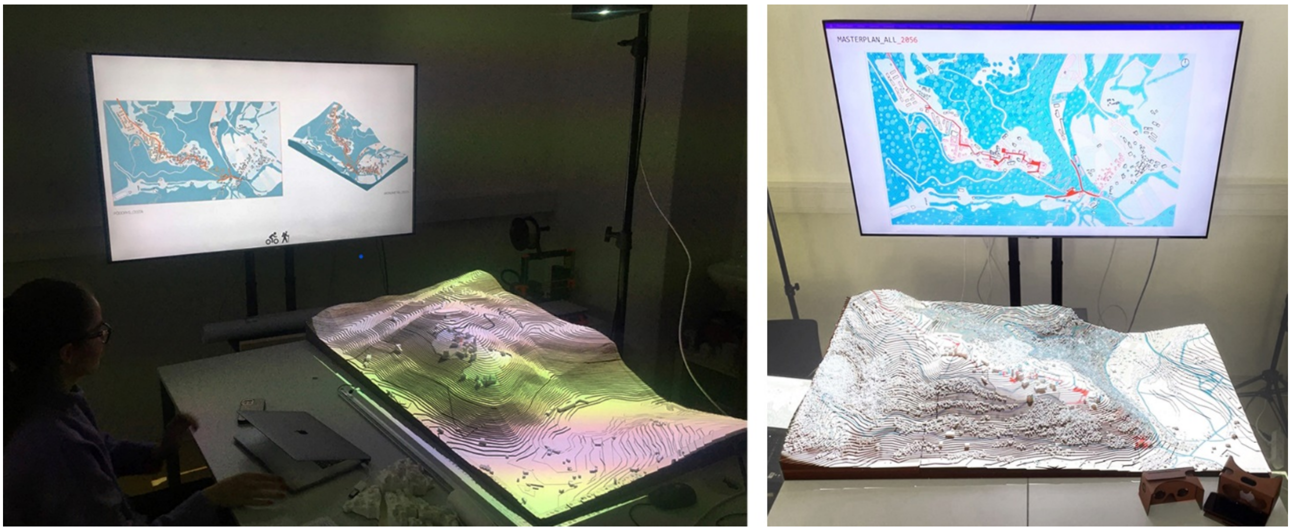


Figure 5: Urban multidimensional model of Accumoli with digital projection from above displaying virtual layers and markers for augmented and virtual reality, developed in Data[LAB] (photographs by the authors).

The plan is to better understand the current state *in-situ* by students using the urban walk - interactive planning method [13] during the participatory planning workshop. The results of these methods could be implemented to the multidimensional model as another layer. Combined with the growing development of haptic technologies, it will be an important aspect for future education directly in the field.

SUMMARY

The method of the multidimensional model provides:

- efficient information transfer and better awareness of development end educational issues;
- reduction of the information asymmetry and clearer identification of the problem and objectives;
- direct and indirect education of students, educators, stakeholders and general public participants;
- deeper understanding of the system's limits and opportunities (variety of ideas came to light);
- increasing internal motivation of involved people resulting from the experience with teamwork;

- higher probability of positive and sustainable results in particular case studies; and
- it is saving time, energy and financial costs to make several identical models - one model for all decision-making processes.

CONCLUSIONS

The case studies of the multidimensional model methodology developed by operational research in Bratislava and interdisciplinary co-operation between various fields in Accumoli proof that through this practical interactive tool, it is possible to educate the general public about the heritage that does not exist anymore or is planned for future sustainable development.

The principle of interdisciplinary co-operation is a synergistic element in a complex scheme of an organised design process and a key educational element in the architectural field. It is possible to embed interactive virtual parts in traditional interpretation with the possibility to control the animations by focusing the view on specific objects. By such kind of mixed media presentation and multi-sensorial stimuli it is possible to achieve a high-immersion experience. The combined methodological framework and the integrated approach to curriculum design [14] in a multidimensional model is an instrument of deeper insights into the topic, potential solutions and side effects facing students, educators, resource managers and other stakeholders. To this day, the results of the presented case studies have been widely accepted by municipalities and the general public, what should have a significant role in further participatory development issues of the local heritage and its neighbourhood. This engagement should bring other observations, new opportunities and solutions which will be the crucial success of this approach.

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