

# The Theatre Metaphor for Spatial Computing in Architectural Design

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## Abstract

New digital technologies require new conceptual approaches to help potential users understand existing and envision new use cases and applications. Moving from desktop computing to spatial computing (virtual, augmented, mixed and extended reality environments) also requires the introduction of new metaphors. New interaction and visualisation possibilities afforded by current devices are causing virtual and real worlds to merge into an inseparable unity of reality and imagination.

There are many similarities between theatre and AEC workflows. However, the theatre process is scaled down in terms of space, time, and budget, and is therefore better suited to explore innovative and experimental methods. In order to conceptualise the role of a novel spatial computing drawing tool (MR.Sketch) in existing AEC processes, we propose the theatre metaphor, which embeds the conceptual foundations of the tool in a collaborative design workflow based on the cooperation of different domain experts.

The metaphor proposal includes the analysis of the following theatre concepts: integrative collaboration with specialists, stage infrastructure, workshops for different tools and manufacturing methods, stocks and the immersive experience of space and time in different scales. We illustrate the capabilities of the theatre metaphor to cover the entire creation and performance process of architectural design in an experimental mixed reality sketching application. The implementation of an early prototype of the sketching application was used to evaluate the applicability of the theatre metaphor to spatial computing.

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## 1. From Desktop Computing to Spatial Computing

When Computing became personal, which happened around the 80's in the 20th Century, new forms of interaction were necessary, that allowed people outside the computer engineering community to work with the operating system and applications. Beside voluminous manuals that explained the technical aspects, metaphors were generated to link well understood concepts to digital ones. User interfaces started with pure text layouts and the used metaphors were commands and menus. Menus should remind people of selecting choices in a restaurant. The development of graphical user interfaces popularized the usage of personal computers even more. Windows, the use of the mouse and the desktop were two-dimensional metaphors that were used for several decades until now. Although the first augmented reality device dates back to the 60's, created by Sutherland [1], spatial user interfaces were not feasible at that time, as the computing infrastructure filled an entire room. The creation of virtual and augmented reality devices in the 90's required to think of spatial ideas for user interfaces.

Greenwold described spatial computing as a concept to integrate physical space into digital environments [2], where computing depends strongly on spatial parameters and spatial events, differing

from computing of spatial data as in classical geographic information systems (GIS) or in building information models (BIM). Spatial computing thus requires mobile devices to be able to interact with space, such as tablets, smart phones, and wearable devices, like smart glasses (see Figure 1).

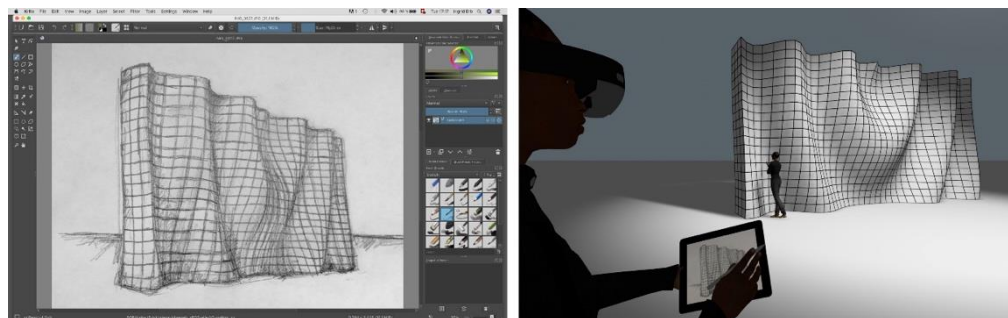


Fig. 1. Desktop computing (Krita [3]) vs spatial computing (Concept visualisation of MR.Sketch)

Beside mobile and wearable devices, other technologies are increasingly enabling spatial computing as computing gets integrated into almost any object, that surrounds us. Smart artificial actors like robots, drones and autonomous vehicles become part of our daily life, also outside industrial applications. We thus see mixed reality spatial computing as an ongoing trend with increasing importance.

## 2. Spatial Metaphors in Computing

Spatial Computing needs Metaphors that relate to well known spatial concepts with user interaction. In the digital spatial domain that ranges from virtual to mixed and to augmented spaces, several metaphors have been used, mostly for information visualization or for virtual reality environments. The landscape metaphor was used by Schreiber and Misiak [4] to visualize software architecture as islands in the sea. Several use-cases for landscapes in information visualization are demonstrated by Fabrikant et al. [5]. An overview of several applications of the city as a metaphor to visualize software is described by Jeffery [6]. A strategy for collaboration in virtual reality was created using analogies from the building site [7]. Many spatial metaphors refer to single rooms like the apartment [8], the curiosity cabinet [9] and the Studierstube [10], [11]. The Holodeck, a concept from the science fiction series "Star Trek" became an often-used metaphor in virtual reality computing, examples are presented by Kymalainen [12] and Raybourn et al. [13].

Laurel made the theatre metaphor for user interface design popular [14], her main ideas were to enable different actors and interactive actions focused around the stage, typically from a proscenium theatre. Her concepts were not focused on the stage as spatial metaphor, as her work appeared first in the 90's and spatial computing was not an issue at that time.

The theatre metaphor influenced others, like in cartography [15] or in a more general work about the narrative in digital media [16]. Even before Laurel, Gould [17] described how programming by rehearsal could help non-programmers to develop software visually.

## 3. The Extended Theatre Metaphor

### 3.1. Concepts from Theatre

Theatre is a total work of art, a *Gesamtkunstwerk*. The notion describes theatre, in particular opera, as an interplay of different arts, including architecture, sculpture, painting, literature, music, and dance. The total work of art not only comprises different arts, but also their perceptibility with different senses.

Theatre is the interaction of the most diverse approaches, art genres, artistic means of expression and practices. Specialists from a wide range of fields contribute their skills. From the very beginning of the project, through all stages of development, a theatre production is characterized by the collaboration and integration of all contributors. The director, choreographer, dramaturge, set designer, costume designer and musical director come together in the preparation phase. Experts from different disciplines are consulted for advice in the early phases of design. Professionals of the most diverse directions work on the execution of the project. Specialists from various disciplines, such as performing arts, visual arts, music, dance, and martial arts, as well as experts and craftsmen of all kinds are involved in a theatre production. Theatre provides a variety of workshops. Every larger theatre has a metal and carpentry workshop, sculptor's studio, decorator, paint shop, department for tailoring and dressmaking, and workshops for making masks and wigs. Stocks with ready-mades, such as set elements and backdrops, furniture, props, and costumes are available. These objects serve as proxy objects for the rehearsal, can be adapted if necessary or used as they are in the performance.

The workflow of a theatre production is comparable to any other creative process and can be divided into preparation, design, and realization. The place where theatre happens is the stage. Scenography, stage design, describes the design of the scene. The scene is the actual heart of the theater. The word scene can mean either "place" or "part of an action" that happens in that place. The notion has therefore both spatial and temporal connotations. Scenography can be the design of spaces as well as the design of temporal processes. All performances require preparations and sometimes extensive rehearsals. Rehearsal is a special feature of the creation process at the theatre. Test rooms are built, and mock-ups and rehearsal decorations are produced in original scale. Fischer-Lichte defines staging as the process of planning, testing, and determining strategies, which aim in bringing forth the performance's materiality [18]. Staging is an intention, it is future-oriented, determined, operative, reproducible and can be fixed in a script or a scenario (see Figure 4).



Fig. 4. Sketch, Model, Rehearsal, Performance, *Idomeneo*, Vienna, 2017, © A. Bardel, M. Buechling

What all concepts from the field of entertainment, gaming industry and indeed theatre have in common is that they offer the opportunity to try out something new and at the same time create the protected space to do so.

### 3.2. *The Relationship between Theatre and Architectural Design*

Scenography is a conceptual tool for creating fictional environments. Although scenography was so far mainly associated with theatre aesthetics, exhibitions, or any other form of staging in the world of entertainment industry it is now increasingly being used in architecture, as demonstrated in [19]. Scenography is a spatial art where various artistic disciplines combine to create an immersive spatial experience. Introducing scenography into the field of architecture also means understanding architecture as an art, the art of building. The creation process in architectural design is comparable to the development process of the theatre production. The design is developed in collaboration with various experts. However, it would be desirable if the integration of specialists also took place in the early design phases, the phases that are actually crucial for the development of the design. In architecture as well as in stage design, the design is determined by numerous specifications, requirements, and constraints. In contrast to theatre, with its great artistic freedom, the design and implementation of a project in

architecture is bound to a strict framework of building regulations and procurement procedures. In both disciplines, the project is sketched in experimental early design phases, revised, and further developed in several steps and finally realized. One of the most important differences between theatre and architecture in the development process is rehearsal. Testing the design of a building, practicing the use of architecture could be a decisive innovation in architectural design. Simulation in different areas, such as static calculations or lighting design, could be used in architecture as a substitute for what rehearsal means in theatre.

### *3.3. Theatre Concepts and Spatial Computing*

To use the extended theatre metaphor for user interface design in a mixed reality spatial computing environment we will apply several conceptual mappings, that link the theatre domain to virtual environments. The creation of any virtual world, e.g., game worlds or architectural design environments, requires various specialists with different artistic and technical expertise like writers, modeling specialists, texture painters, software developers, sound designers, etc., thus also creating a total work of art. Technologically, multiple senses must be considered, like visual, auditive and haptic. The creation process of a theatre production can also be mapped to the design of virtual worlds. The integration of specialists demands a digital multi-user environment, which might consist of different views, tools, and corresponding mappings of the real environment to a virtual environment. Simulations, that link the simulation domain to the design domain, preferably in real-time, would greatly enhance the design, allowing rehearsal phases to be applied in the design development. In any creation process, the use of stocks of previously designed objects, play an important role, as with digital assets and software libraries. As virtual worlds take place in a spatial and temporal framework, scenographic strategies need to be linked to virtual concepts, like digital storyboards, semantic descriptions of spaces and activities. Limited space, through the stage dimensions, and limited time, through the length of a play require spatial and temporal scaling, also needed to map any virtual environment to a physical surrounding. The dualism of stage and auditorium, as well as the creation process of a production and its performance can be transferred to any development process and the use of a virtual environment. As theatre can provide a test environment for architecture, it can play a similar role in testing virtual worlds in a mixed reality surrounding, needed to develop new artistic and technological strategies.

## **4. Developing a Mixed Reality Sketching Application for Architectural Design**

The following part describes the development of a mixed reality sketching application as part of a larger research project about advanced computational design (ACD). ACD consists of several sub-projects in the areas of design methodology, visual and haptic design interaction and form finding. The sketching application targets the early phases of architectural design and integrates several computational tools that will allow design evaluation in a much earlier phase than possible before.

### *4.1. Sketching Strategies*

Sketching is mostly seen as the preliminary step of drawing. But sketching is more than just a tool for the first visualization of the design. By combining reality and imagination in a continuous creative dialogue, sketching reveals the intrinsic meaning of an idea (see Figure 5). The first approach to sketching is the connotation with scribbling and doodling. In its development from doodle to design, sketching can be interpreted as form finding. Sketching can also be a systematic strategy of design. From point and line to plane and volume means to characterize sketching as a structured method or a methodology. However, sketching is more than a means of expression. It is also a selection procedure. Sketching means making decisions. Every point, every line, every object, every situation, is a choice.

Sketching is the art of omission. One of the most important aspects of sketching is probably the duality of fact and fiction. Every idea can cause reality, and every existing part of this world can cause a new idea. Sketching is an inner dialogue of what is real and what would be possible. In this sense, sketching can become a tool for thinking.



Fig. 5. Sketching a wall: Drawing and painting, Sculpting, Collage, Ready-made

#### 4.2. Digital Sketching in Three Dimensions

Digital sketching in two dimensions (2D), simulating pen and paper, is available in multiple commercial and open-source applications. To be able to sketch in three dimensions (3D) is an ongoing research topic, as there are still several difficulties to solve. Some of the research questions in that areas are: How to use 2D input devices for 3D sketches? How to create direct 3D input? How to create sketches with a context of real objects?

To use current available 2D input devices, like tablet and pen, several approaches create canvas in 3D, e.g. planes or curved surfaces and project 2D strokes onto 3D canvas [20]–[22]. As tablets are used in many cases for 2D input, some approaches track the location and orientation of the tablet to generate 3D canvas [23]. The use of hand gestures was used to create 3D canvas from the hand movement, while using a tablet to create sketches projected onto the canvas [24].

Google Tiltbrush [25] became well known of painting in virtual reality (VR) with inputs from VR controllers, that can track movements in 3D directly. An overview of several painting applications in VR is given by Ramsier [26]. As was shown by Arora et al. [27], a challenge for precise drawing in 3D is the lack of haptic feedback. Müller et al. address this issue by using a Phantom device [28].

Some examples of sketching within a context by augmented reality (AR) techniques are provided by Yee et al. [29], Bergig et al. [30], Paczkowski et al. [31] and Wacker et al. [32].

#### 4.3. A Mixed Reality Prototype

To evaluate the theoretical concepts in practical experiments, we implemented several iterations of a sketching application prototype. We chose the Unity game engine [33] as platform for implementation, as it allows for rapid prototyping by providing built-in functionality in areas outside our scope such as rendering, input handling and cross-platform targeting. The application was designed to provide the following key features:

- Mobility: The target platforms are tablet devices with stylus input to retain the immediacy of sketching.
- Collaboration: Multiple artists and specialists can work simultaneously, but independently on the same project. Additionally, it is possible to exchange data with other applications in real-time.
- Mixed Reality Interaction: The virtual space of the application is strongly connected to the real surroundings of the artist. Navigating the virtual space of the sketch is possible via moving around in real space. Real physical objects can be used to create and manipulate drawing elements.



The following sections describe the specifics of how concepts from the theatre have been realized as functionality in the application prototype.

#### 4.3.1. Stage and Light Infrastructure

The stage serves as the anchor point of the drawing in the virtual 3D space. It provides the bounds and the landmarks for navigation and a sense of scale for the drawing. The aforementioned mixed reality spatial navigation mode works by tracking the position and orientation of the tablet device and use it as a window into the virtual environment. Beside this mode, the application also allows to navigate the virtual space via touch gesture control. As described above, bridging the 2D→3D input problem in an intuitive way with a single viewport is non-trivial. For the touch gesture control in particular, the stage is a key component of efficient and precise spatial navigation and positioning. The landmarks of the stage provide a framing, lowering the time and cognitive effort expended on finding the specific pose in 3D space from where newly sketched lines connect to the drawing in the desired manner.

In the context of spatial navigation, the stage can also be used to register the virtual space to the real physical space around the artist. The application prototype also allows to scale the virtual space and the drawing independently from one another and from the size of the physical space. This functionality is utilized for collaborative work as well, where different artists can observe the drawing from different scales: As one artist sketches on blueprint scale, the other one can traverse the sketched architecture at a real-world scale.

To selectively combine parts of a sketch, 2D drawing applications use the metaphor of layers. Since layering in this manner does not make sense in 3D space, we propose the concept of the fly loft for this purpose. Closely related to the spatial concept of a stage, the fly loft allows to combine partial sketches by raising and lowering the flies they are affixed to. The prototype allows to target and control specific flies to experiment with different combination of forms.

The concept of staging is also implemented as a functionality. The prototype allows for activating a "revolving stage", a smooth animated rotation of the 3D sketch around the center of the stage. This motion is independent from the spatial navigation. Staging the artwork in such a manner facilitates the sense of structure and dimension and aides the process of form finding. To further this, the application also features a mixed reality mode that allows augmenting markers with computer generated imagery. The prototype utilizes image tracking to import and scale previously saved sketches and anchor them to printed-out markers. Artists can use physical objects for comparison or framing to evaluate their design created in the application (see Figure 6.).

Working with lights is closely connected to this topic as well. MR.Sketch allows the artist to control different aspects of the lighting infrastructure. Directional light and constrained, parametric light fixtures (pars, spotlights) can be activated. Furthermore, it is possible to import photometric data for use in lighting setups in the application. Refer to Figure 7. for a comparison of the rendering visuals. However, lighting simulation is a vastly more complicated task, demanding specialist domain knowledge to meet the requirements of architectural design as well as the needs and ideas of the client (e.g., atmospheres). For a description of our approach to domain knowledge synthesis in the application, refer to Section 4.3.3.

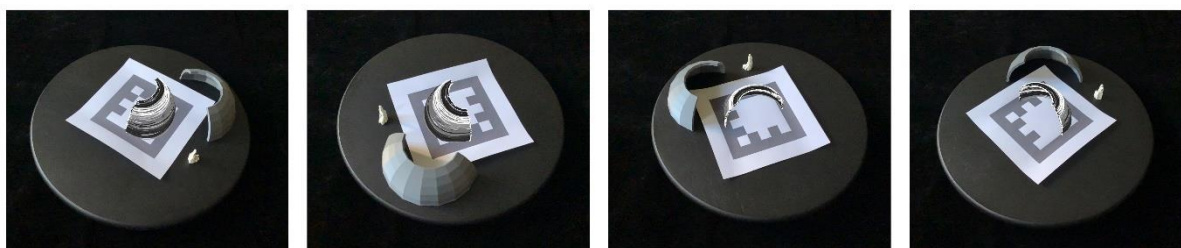


Fig. 6. Mixed Reality Turntable simulating a rotating stage}

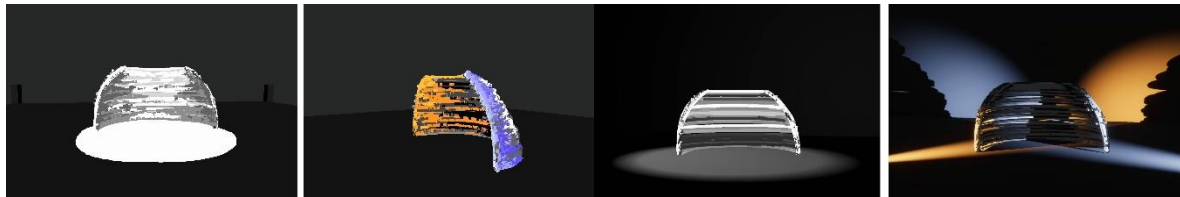


Fig. 7. Left: Sketched light situations, Right: Simplified rendering vs. High definition rendering

#### 4.3.2. Stocks: Physical and Virtual Ready-Mades

Another key strategy in aiding the process of sketching into 3D space via a 2D input surface is also closely related to concepts from the theatre. The concept of stocks, meaning collections of reusables, organized and catalogued ready-mades, translates well to the approach of constructing complex structure from pre-defined shapes during the process of form finding. The prototype realizes this concept with two features: The use of virtual and of physical ready-mades.

To make use of physical ready-mades, MR.Sketch allows artists to instantly create a mesh representation of the physical object inside the virtual space of the sketch. The current target device of the application is an Apple iPad Pro 2020, featuring spatial meshing capabilities via a built-in lidar depth mapping sensor. The prototype utilizes this capability to create a virtual representation of the physical object, which then can be used as drawing canvas. Figure 8. depicts the scanning of a seat and it's use as drawing canvas.

The prototype also enables artists to browse through stocks of virtual ready-mades, different 3D models imported from other modeling and miscellaneous content creation applications. After selecting an object, it is possible to use the 3D mesh as virtual canvas to reuse parts of their shapes, akin to the physical stocks. Figure 8. demonstrates this as well.



Fig. 8. Physical and virtual stocks: Using objects from stocks as drawing guides, Left: Scanning a physical seat and using it as virtual canvas, Right: Similar type of chair from the virtual stocks (Model by K. Albayrak [34])

#### 4.3.3. Integrative Collaboration with Specialists

As in theatre production where many experts in different disciplines come together to develop a scenography and provide feedback for the production team, the designer needs feedback from specialists, often generating complex simulations to evaluate a specific sub-goal. We translate this aspect to a specialized organization of creation tools in the sketching application prototype, apart from a collection of "belt tools" (e.g., pencil, measuring tape, colour palette), tool sets and actions are organized in ateliers. Ateliers have their own workflow specific to the task to perform and provide interaction modalities to aid this workflow.

Further expanding upon this notion, the application is set up in a way to integrate other domain-specific software through these ateliers to improve the decision making in the design process. We aim at providing real-time feedback even in the early phases of design, during the sketching of ideas, where not every part is completely specified. The prototype facilitates integrating other software created by our research partners, such as simulations of different material properties, lighting, panelling or foldable structures.

At this point in the development progress, two approaches have been implemented. One approach enables the integration of our sketching application with the 3D modelling software Rhino [35], more specifically with its parametric, visual scripting environment called Grasshopper. The ACD Sub-Project researching "Flexible Quad-Surfaces for Transformable Design" provided the Grasshopper plugin "Scutes" [36] that generates a parametric flexible surface of revolution. The prototype provides the option to sketch the input (the profile curve for a surface of revolution) for this script, which is packed and sent via network connection to a Rhino.Compute instance. This allows accessing the Rhino and Grasshopper SDKs through a stateless REST API running on Windows Servers [37], and provides the generated mesh in response. The generated mesh is inserted and visualized in MR.Sketch. Figure 9. showcases a sketched surface which provides input elements for the script and a visualization of the resulting parametric mesh in Rhino.

The atelier for lighting design contains tools to facilitate integration with our partner at the ACD Sub-Project "Researching Lighting Simulation for Architectural Design". The prototype lighting tools consist of paint-able light and shadow areas, that can be sketched like the basic lines of the drawing, but instead of positioned freely in space, the lights and shadows can be layered onto previously sketched surfaces. Sketched geometry and painted light/shadow are exported via the glTF format from the prototype. From this data, the lighting simulation specialist's software calculates possible light placement combinations that would approximate the sketched lighting conditions within a given set of constraints. (Light fixture types, placement positions, etc.) Figure 7. illustrates different sketched light situations.

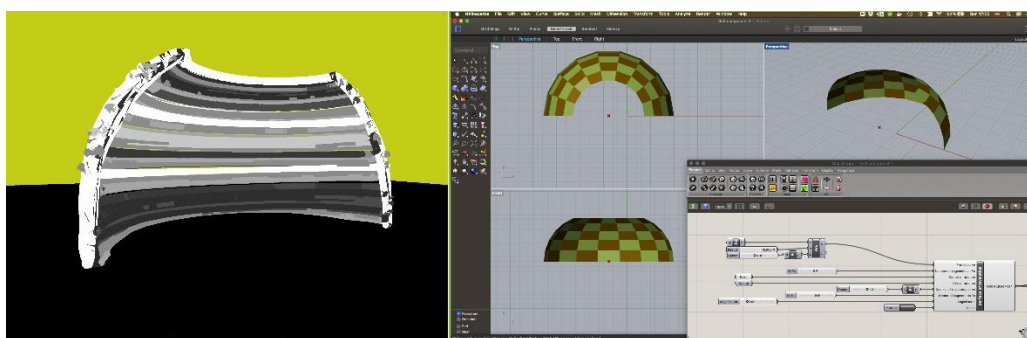


Fig. 9. Integrative Collaboration with Specialists: Parametric Objects in the Sketching Application

## 5. Conclusion and Future Work

We described an extended version of the theatre metaphor, that includes the creation process of a theatre production as well. After relating the creation process of the theatre to the development process of architectural design, we transferred selected theatre concepts (total work of art, integrating specialists, staging, rehearsal and stocks) to the field of spatial computing. The implementation of the theatre metaphor by means of a mixed reality sketching application makes spatial computing a suitable environment for experiments and innovation and can be applied in architectural design as well as in other disciplines. We described practical applications of these ideas via selected experimental features of a prototype (MR.Sketch).

Future work will expand upon the theatre metaphor by further transfer experiments. We intend to translate the concept of interpretation as a layer of semantic attributes to sketches and the perceived physical environment in our mixed reality application. We will implement expert collaboration as the integration of domain knowledge about architectural design, by utilizing machine learning. For data exchange, a general database of material properties, that fulfill several requirements, like mechanical, optical, and haptic behaviour needs to be incorporated into the application. Through adding audio interfaces and by integrating large-scale haptic feedback our mixed reality sketching application will be extended to other senses, that might be useful for improving user experience and finally architectural design.



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