Synthetic Space: Inhabiting Binaries



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Abstract

In this paper we propose the concept of Synthetic Space—architectural space fused with the properties of digital bits. Past efforts at integrating digital technology into architectural space have generally assumed architecture to be a stable, invariant background onto which layers of digital information/devices/services can be overlaid. In Synthetic Space, however, this stability is instead superseded by the capricious plasticity of digital data. For future inhabitants of Synthetic Space, transforming the makeup of the surrounding built environment will be a trivial, effortless task, equivalent to changing the wallpaper image on a modern-day PC or smartphone.

Keywords

Synthetic Space; digitizing architecture; habitable bits

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous

General Terms

Design; Human Factors

Introduction

Occasionally we see writings that, in hindsight, prove to show uncanny levels of accuracy in their predictions of future technological advances. "The Computer for the New layers of digital information/devices/services (malleable)



Physical architectural layer (static)

figure 1. "Virtuality" only spreads within newly created digital layers.

21st Century" [19], the famed essay by Mark Weiser, has undoubtedly carved out its place as a strong addition to that venerable tradition. The recent talk of a "post-PC era"—the argument that PCs are becoming overthrown by a new generation of digital devices—is all but an exact facsimile of Weiser's words, with only small differences in terminology (Weiser uses "tabs, pads and boards" instead of "smartphones, tablets and interactive surfaces").

In the essay, Weiser offers the following, succinct description of the essence of his vision:

The "virtuality" of computer-readable data—all the different ways in which it can be altered, processed and analyzed—is brought into the physical world.

An eloquent statement, that more or less summarizes HCI innovations over the past 20 years. Indeed, the various research concepts/initiatives—e.g., mobile computing, tangible user interfaces, ambient displays, augmented reality, tabletop/surface computing—have all contributed to the gradual and steady injection of virtuality into the physical world.

However, upon close inspection we find that instead of virtuality fully permeating through the physical world, these developments have culminated to form new auxiliary layers of digital information/devices/services atop a (supposedly) neutral background layer of static architecture, i.e., the traditional built environment composed of ceilings, walls, floors and windows. Digital plasticity flourishes, but only on the auxiliary layers; it never invades the architectural layer, which is assumed to be invariant (Figure 1). This attitude is implicit but prevalent. Augmented reality guides on smartphones merely add "panels" and "bubbles" onto an otherwise unchanged city scenery, and touchscreen walls only permit digital interaction with the 2D graphical contents displayed on their stationary surfaces.

The Achilles' heel of this attitude is that architecture has never been, and presumably never will be, a neutral background layer. Studies have shown that our behaviors, thoughts and even emotional states are strongly influenced by the design of the environment, both indoors and outdoors [3, 15]. To use an example rooted in our everyday lives as researchers, we will struggle to write academic papers, even if provided with a (hypothetical) perfect word processing software on a perfect laptop/tablet, if the design of the environment is not conducive to such activities (this paper was mostly written at a greatly conducive café near Harvard; trying to write at the local hamburger place never yielded quite as good results).

What we are now witnessing is the spread of virtuality strictly under the reins of architecture. For us to truly infuse the benefits of virtuality throughout the physical world, we must digitize architectural space—or to use our own terminology, realize *Synthetic Space*.

Synthetic Space

We define Synthetic Space as architectural space fused with the distinctive properties of digital bits—ease of modification/duplication/distribution, etc. It is a concept that we anticipate to gradually become reality over the next 10 to 20 years; we are not envisioning some kind of a far-future science fiction wonderland, where the entire built environment is made up of freely shapeshifting programmable matter. Rather, we see it as the product arising from the introduction of a range of

Environment

Sensors/actuators/displays etc. embedded within the architectural environment

Individual Personalized technologies, e.g., mobile and wearable devices

figure 2. Categorization based on locus of technical apparatus.

Degree of adherence



figure 3. Categorization based on degree of adherence to existing architectural conventions.

technologies that collectively chip away at the stability of the traditional architectural environment, leading to the experience that we are living within a world of *habitable bits*. The nature of these technologies can vary greatly; one way of categorizing them would be to look at whether the technical apparatus resides within the *environment* or on the *individual* (Figure 2).

Technologies that reside within the environment may include mechanical setups that literally change building structures (somewhat like the vehicles-robots in the movie *Transformers*), and those that reside on the individual may include augmented reality goggles that alter our visual perception to create the impression of flexible space. Technologies can also consist of various combinations of mechanisms installed on both the environment and the individual—which is why we consider these two categories as end points of a single continuous axis, rather than a set of two discrete and mutually exclusive states.

The locus of technical apparatus, generally speaking, correlates with the degree of granularity with which the technology can operate; those wholly residing in the environment tend to broadly affect every person within its reach (though exceptions can exist), while those entirely installed on the individual can often customize their effects to each user. This is a corollary of the fact that technologies leaning on the individual side typically function by manipulating users' perceptions, instead of exerting actual changes to the environment.

Questions may arise about whether technologies that hold no actual power over the environment itself should even be included in discussions on Synthetic Space. However, we consider the crux of Synthetic Space to be the experience not the technology, and thus opt for an eclectic stance that eschews arbitrary preconditions about *how* that experience is achieved.

Another way of classifying the technologies is to focus on their attitudes toward our preconceived notion of architectural space—the timeworn, pancultural image of rationally delineated space, composed of walls, floors, ceilings and windows (Figure 3).

Here *conservative* refers to a class of technologies, that add extra layers of flexibility to buildings while still generally conforming to traditional ideas about the makeup of architectural space. These technologies are usually designed to provide digitized counterparts to existing components of the built environment (walls, floors, etc.), and depending on the degree of adherence to conventional ideas, they can be further categorized into *literal* and *metaphorical* technologies.

Literal technologies take a strictly traditionalist stance, faithfully retaining the experiential qualities of "classic" architectural space. The technologies are commonly mechanical; a notable example is *Maison à Bordeaux* designed by Rem Koolhaas, where the entire floor of a room is in fact an elevator that moves up and down within the house. With each move of the elevator the spatial logic of the house is renewed, but within each static state (i.e., when the elevator is standing still) the experience offered is precisely that of a conventional architectural environment—a visitor may quite possibly not notice the dynamic capabilities of the house, until a transformation is actually observed.

This is in contrast to *metaphorical* technologies, which introduce markedly foreign elements into the makeup

of architectural space, that are nonetheless designed to operate along conventional architectural metaphors. Our experimental research prototypes, described later in this paper, all fall into this category. For example, the *Weightless Wall* system generates sound-blocking (but invisible to the eyes) virtual walls; the resulting experience is a radical distortion of soundscape unseen in traditional architecture, but the technology is still designed to have metaphorical similarity to real walls, allowing users to form clear, rational expectations (*mental models*, in Donald Norman's terminology [12]) about the functionalities and effects of the technology.

Progressive refers to the yet largely unexplored class of technologies, that introduce novel ways of delineating space that do not conform to traditional architectural metaphors. We foresee a gradual emergence of these technologies, after conservative technologies have won solid adoption. The end effect will be a drastic shift in how space is defined—the built environment will be made up of collections of yet unnamed digital elements, not merely software-controllable counterparts to walls, windows, ceilings, etc.

Other useful categorizations should arise with further investigations. As for now we have used the above two categorization schemes, in sorting out prior work and planning our own research strategies.

Related Work

To be fair, humans already manipulate space using technology on a regular basis. Calling someone on the phone instantly *compresses space*, and portable music players can erect *auditory walls* between us and the environment. Such developments have led scholars to proclaim (perhaps somewhat prematurely) "The Death of Distance" [4] more than a decade ago, and laid the foundation for a new, multidisciplinary field of study that we now call urban informatics. The entire scope of space-altering technologies is practically unlimited (do carrier pigeons compress space?). Here, we provide a concise overview of related work, where we only regard works as related to Synthetic Space if they exhibit the following two traits: 1) an awareness of the power of physical architecture to influence human behaviors and psychology, and 2) an intent to let users neutralize, or take control of, that power of architecture.

Naturally, it is architects who have been most attentive to the power of their art. The prospect of dynamically shape-shifting buildings ("kinetic architecture" [22]) has long interested architects, resulting in commercially successful constructions such as revolving restaurants, and also in fantastic unbuilt visions such as Archigram's Walking City [5]. Recently, parametric modeling tools have enabled architects to inject increasingly complex transformation mechanisms into building shells, and the introduction of accessible sensor/actuator platforms (e.g., Arduino) has led to a new field of responsive (or interactive) architecture [7]. Typically, architects rely on large-scale mechanical configurations to add flexibility to buildings (a notable exception to this is the growing use of "smart", or switchable, glass).

Within the scope of computer science, appreciation for the power of architecture has been most clearly evident in telepresence and CSCW research. Early systems for remote collaboration [6] provided little more than live video feeds of distant office rooms, but the growing understanding of the roles of workspace awareness and nonverbal communication cues has continually pushed research efforts into the direction of ever-closer spatial integration. The Office of the Future [14] takes this direction to the extreme; by projecting real-time video onto entire walls of office rooms, the system attempts to make remote workers feel as if they are in a single, connected room. In a smaller-scale example, MultiView [11] extends the simple video conferencing system to achieve a sense of spatial coherency across the two connected rooms—letting users make eye contacts with workers in the opposite room. Systems have also been developed that create the impression of shared spaces using wearable technologies, e.g., HMDs [8].

The entire concept of ambient displays [20] is built on the recognition that the architectural environment can convey information in subtle and unobtrusive ways. However their actual implementations often fall short, typically being no more than abstract display devices installed on walls/ceilings—the physical architectural layer is kept perfectly intact. Nevertheless, the concept is highly relevant; studying how digitized architecture can act as a robust ambient display platform should be an important line of Synthetic Space research.

Among commercially available applications, augmented reality city guides on smartphones [1] may perhaps offer the closest approximation of the Synthetic Space experience. Still, partly due to limitations in mobile computing capacity, these applications unquestioningly confine the urban scenery to the role of an indifferent, static backdrop—a flaw addressed in *ClayVision*, one of our experimental research prototypes.

Turning our attention to more futuristic technologies, self-reconfiguring modular robots [21] seem to possess vast potential for flexible architecture. Though generalpurpose programmable matter is still decades away, near-future research efforts could focus on limited, application-specific implementations for concrete usage scenarios/domains.

Within the categorization scheme we introduced in the previous section, the *literal-environment* segment is mostly occupied by kinetic/interactive architecture—the architects' approach to Synthetic Space. A major issue with these technologies (arising from their typically mechanical nature) is their often steep costs, that limit their feasibility for adoption in everyday environments. *Literal-individual* is currently empty; the segment's strict inclusion requirements can be met by no less than an individual augmented reality system that faithfully reproduces all sensations (visual, aural, haptic, etc.) relevant to the experience of architectural space.

The *metaphorical* segments are where most prior work within computer science belongs. These technologies, both the *environment* and *individual* varieties, normally allow for higher degrees of plasticity compared to literal technologies, at much lower costs. These segments are where we expect to find the most short- to mid-term application potential, and where we thus plan to direct our resources in our near-future research attempts.

Some time will be needed, before concrete examples of *progressive* technologies begin to appear. In his essay, Weiser predicted the adoptions of tabs (smartphones) and pads (tablets) to be necessary prerequisites for the adoption of boards (interactive surfaces). We anticipate a similarly stepwise acceptance of Synthetic Space technologies—conservative technologies will provide the initial scaffolding, for the belated arrival of progressive technologies and the ensuing injection of new syntactic rules into the design of the built environment.



figure 4. Weightless Wall hardware configuration.

Touch-screen input





Tangible interface





figure 5. Interaction techniques for manipulating "walls".

Semi-automatic layout optimization using furniture positions



Experiments

We have built three experimental research prototypes, *Weightless Wall, Gilded Gait* and *ClayVision*, to kickstart our own efforts at developing novel Synthetic Space technologies. The prototypes all adopt a metaphorical approach, generally adhering to traditional architectural metaphors. Also, the technologies all have an individual slant; the prototypes are in effect products of our early explorations, on how personalized augmented reality technologies can be used to alter human perceptions of architectural space (with each prototype dealing with a single channel of perception—sound, touch and sight, respectively). This is a reflection of our decision to start our development efforts with small-scale projects, with limited time and budget requirements.

Although we call them experimental, the prototypes are not merely conceptual sketches. Rather, they are well developed, functioning systems, with enough technical depth and novelty that each of them can stand on its own as an independent research project. Here, we are again following in the footsteps of Weiser and his colleagues at Xerox PARC—as in the words of Alan Kay, we believe that "the best way to predict the future is to invent it". We are intent not only on theorizing about Synthetic Space and speculating about its implications, but also on turning the concept into concrete reality through extensive technical developments.

Weightless Wall

Weightless Walls [17] are sound-blocking virtual walls, created using custom pairs of headsets. Each headset, which is in fact a pair of noise-canceling headphones equipped with a microphone and a location-tracking ID tag, acts as a "smart" transceiver that allows users to engage in *spatially correct* conversations—the voice of a person in the left side of the user will actually sound like it came from the left. As the headphones cancel out most natural sound entering the users' ears, the setup effectively allows all conversations between users to be computationally filtered inside the central server. With this setup, realistic sensations of sound-blocking walls can easily be produced, by tweaking the server process so that users' voices will only be transmitted to other users in the same sides of the virtual "walls". Figure 4 illustrates the hardware configuration.

The walls are purely digital; they have no real physical presence other than lines projected onto the floor from above, and thus their layouts can be instantaneously modified. We imagine that in the future office, all workers will be wearing tiny headsets on their ears and





Fill the path to the station with bumpy tiles...



figure 6. Gilded Gait.



will engage exclusively in computationally mediated conversations, creating virtual walls whenever they feel the need to have quiet conversations.

We have built and experimented with three different techniques for manipulating wall layouts: touch-screen input, tangible interface, and semi-automatic layout optimization that works by estimating worker activities from furniture positions (Figure 5). The last technique is especially important—automated adjustments of wall layouts have the effect of enabling office space to be treated in the same way that memory is treated in PCs; as a shared resource open to dynamic allocations, and whose usage is optimized in real time according to the collective activities of occupants. "Rooms" of virtual walls can dynamically expand or shrink, based on the real-time necessities of the workers inside them.

Gilded Gait

Gilded Gait [16] is a novel haptic interface system that alters the perceived physical texture of the ground, by mechanically augmenting footsteps with vibrotactile patterns applied to the user's foot soles (Figure 6). The technology is basically borrowed from prior work on vibrotactile feedback for touchscreens [13], only in this case the system takes the form of a pair of thin insoles that can be inserted within footwear. The system allows for low-key, unobtrusive information display, which makes it particularly suitable for outdoor uses such as urban navigation. For example, a user can make the entire ground of the path leading to his/her destination (e.g., hotel, train station) have a fake "bumpy" ground texture. The end effect may be described as enabling users to dynamically place *tactile warning tiles* (bumpy tiles commonly found in urban areas in Japan and the US) in arbitrary locations throughout the city, although



figure 7. Artificial "ground texture" patterns.





figure 8. ClayVision.

the analogy is not complete (i.e., not *literal*) due to the effect being limited to haptic sensations.

Our built prototype can simulate three different types of ground texture (Figure 7). Though the effects are still crude and are nowhere near indistinguishable from real ground textures, the prototype already offers discreet information display that truly functions at the periphery of user attention.

ClayVision

ClayVision [18] is an augmented reality city guide for mobile devices, that overlays information to the city not by pasting "panels" or "bubbles", but instead through real-time 3D transformations of built city elements. The system dynamically analyzes and reassembles the city into a better-designed copy of the original, that is both easier to navigate and also can be tailored to suit the individual needs of users (Figure 8).

In urban planning, it has been well known that the city scenery is inherently expressive—it actively conveys information to pedestrians/drivers, providing important cues for navigation [10]. ClayVision allows users to control this expressive potential. For example, buildings relevant to the user's current needs can be made taller while irrelevant ones can be torn down, or fake visual attributes can be assigned to facades to make buildings more expressive of their usages. The range of possible transformations is expansive; many techniques used in urban design practice should be directly applicable as functionalities of ClayVision.

Technically, the system relies on accurate localization based on computer vision to dynamically map 3D city models onto video frames. A simplified version of SIFT

Changing heights

[9] is used to make this process run in real time on an off-the-shelf tablet device. Once the model is mapped, all of the buildings in the video frame can be considered and treated as textured 3D models, and will be open to freeform transformations. Although our prototype only functions in limited locations at this moment, otherwise the experience of the system is already fully realized. In the future, we expect ClayVision to run on wearable, glasses-type displays instead of tablets, allowing users to altogether forget about the real city and spend all their time in its "filtered" copy.

Prospects

Research on Synthetic Space is still at a nascent stage; prior work, including our experimental prototypes, has merely scratched the surface of the concept's potential. In the short-term future, research efforts should focus on establishing a small set of key technologies (likely metaphorical) that can spearhead public adoption of Synthetic Space—the concept's equivalents to Weiser's "tabs, pads and boards". Fulfilling this goal is crucial in elevating Synthetic Space from a loose, fragmented assemblage of technologies into a credible platform for next-generation computing. In the long term, research attempts should gradually shift their attention towards explorations of progressive technologies.

Even more intriguing than technical developments may be the theoretical, philosophical and socioeconomic implications of Synthetic Space. Below are some of the questions that may merit further investigations:

• What will be the effects on the architecture industry? Will we see changes as drastic as those that occurred in the music and publishing industries, following the introductions of digital music and e-books?

- Can the phenomenological aspects of the architectural experience—qualities claimed by Gaston Bachelard [2] to elude reductionist treatments (and what Peter Zumthor calls the *atmosphere* [23] of space)—ever be digitized?
- Will the public play a greater role in spatial design? Could the DIY-ethos of open-source hardware/software communities permeate architectural design as well?
- How will Synthetic Space impact our future lifestyle? Will it be utopian or dystopian? Will it be aesthetically (and ethically) desirable?

Architecture has always been regarded as being more than an art of construction; the practice and its outputs have multiple, inseparable layers of cultural, aesthetic and philosophical meanings attached to them. This characteristic breadth of architectural discourse should be reflected in Synthetic Space research as well.

Conclusion

In this paper we described the concept of Synthetic Space—architectural space fused with the characteristic properties of digital bits. The concept brings together multiple, independent streaks of technical development and weaves them into a single, coherent vision, that is both innovative and solidly rooted in past HCI thinking. Although we are still at an early phase of research, our three experimental prototypes already demonstrate the concept's capacity to trigger developments of novel and practical technologies.

We now live in an era where fresh, bold ideas are eagerly being awaited with respect to the design of the built environment. Growing interest in environmental protection and the global phenomenon of urbanization are just two of the myriad reasons why a sweeping overhaul is being called for in architecture and urban planning/design. This situation presents a ripe condition for introductions of Synthetic Space technologies. To engage in Synthetic Space research means to partake in innovations that are not only technically/theoretically interesting, but may possibly be of considerable social, political and ethical significance.

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