The Hyphae House and the Paperless Worksite

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Abstract. This paper discusses Augmented Reality on smartphones as a tool for building complex structures without utilizing CNC technology while showcasing architectural research. A 1:1 prototype made of concrete blocks was built to test the current stage of this technology, along with an interactive virtual exhibition. Results showed a positive outcome regarding possibilities to use the accessible technology of smartphones as a complementary tool, both in the construction site and to computerize construction work nowadays. Despite tolerance issues in the placement of blocks, the technology proved effectful as a construction and visualization method.

Keywords: Augmented Reality, Biomimetics, Education and Design, Prototyping, Parametric Design

1 Introduction

The Hyphae House is a built prototype that speculates on collaboration methods between machines and humans on the construction site. If in the 1990s the possibility of designing architecture without paper support was explored (Norman, 2001), in 2021, we explore the construction phase without printed construction drawings. We present a process that uses Augmented Reality (AR) via smartphones to communicate and visualize the parametric model for physical construction by humans, including architecture and design students and construction professionals.

The artefact's broader conceptual context is "the minimal essential house", resulting specifically from a biomimetic approach that focuses on the structure and growth process of the mushroom, particularly its hyphae (branched filamentous structure or mycelium) (Gruber, 2017; Imhof; 2017; Henriques et al., 2019).

An AR exhibit about the project and its construction was also created to extend the didactic and hyper-reality nature of the experience (Tiffin, 2001; Terashima, 2001), allowing access to virtual content as the metalinguistics of the process.

2 Methodology

2.1 Prototype

The prototype development was part of a postgraduate degree program in design technologies focusing on contemporary technologies in architecture and design, biomimicry, parametric modelling and AR tools, which culminated in a 1:1 scale object. We discuss the potential and limitations encountered in the design and construction process of such object.

The hyphae, long cylindrical fungal cells with multiple nuclei, were the inspiration for form generating. The design involved a hybrid process, including remote and in-person participants, who used various tools and media, such as mock-ups in multiple scales, 3D prints, parametric models, sketches, renders, and numerous visualizations of the proposals in 1:1 scale, in AR (Figure 1).

The parametric model allowed for rapid adaptation to the site. In order to define the object placement, we chose to emphasize specific pedestrian flows by reinforcing existing circulation patterns. As a result, three fluid and sculptural septa were configured, allowing for negotiating with said flows and housing new spaces for coexistence.

Figure 1. AR visualization of the proposal. Source: Authors, 2021.

Hollow concrete blocks, measuring 29cm x 19cm x 14cm were the main building material. Produced by a local partner company, the intention was to demonstrate that an ordinary product could generate complex geometries, moving away from the traditional parallel stacking of blocks. This choice was inspired by the High-Low aesthetic (Locatelli et al. 2018) that proposes the rearrangement of local and low-tech materials via digital modelling.

There was also an interest in the so-called Discrete Architecture (Retsin, 2019), where digital modelling focuses on the possibilities of arrangement, or aggregation, of a kit of finite, repetitive and interchangeable elements, in contrast to the hegemony of the curvilinear language in digital architectural production of the last three decades.

The generation of the prototype form emerges from the negotiation between the parts and the whole, situated between the latter's imposition over the parts (as in the curvilinear tradition) or in the autonomy of the parts concerning the whole, as in the Discrete Architecture proposals. Thus, curvilinear forms were "discretized" into repetitive elements parameterized for construction.

With the application of parametric modelling and AR in our experiment, a pre-existing industrialized material was used to generate unique forms. This harks back to the existing tradition of using bricks or blocks to create rotation-driven visual effects in architecture. Perhaps the most paradigmatic case is the fabrication of the walls of the Gantenbeim vineyard by the Gramazio & Kohler research group at ETH Zurich in 2006, when a large robotic arm on a linear axis was used to prefabricate facade panels (Figure 2).

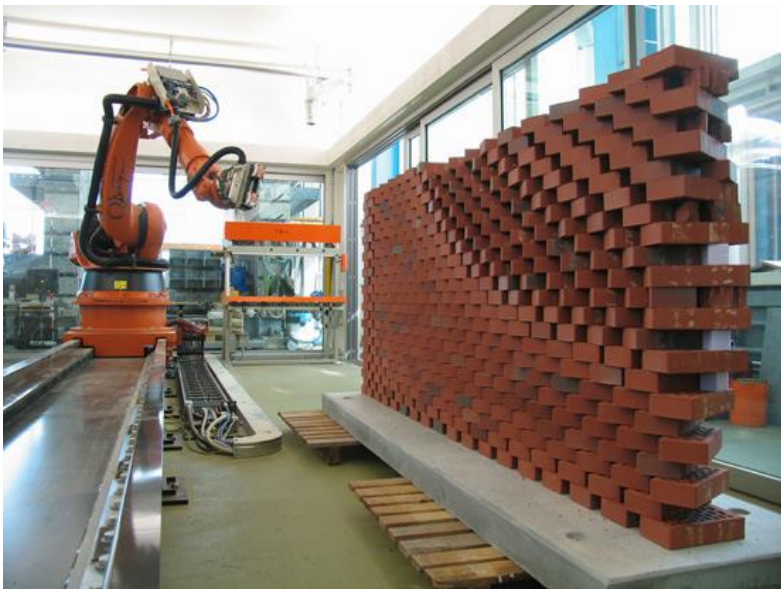

Figure 2. Manufacture of the masonry in the Gantembem vineyard. Source: ETH Zurich, 2006.

In the South American context, the "Coblogó" project, developed by SUBdV in São Paulo, envisaged a method in which concrete blocks were located at specific angles in the façade, using more straightforward and more economical digital fabrication machinery and labour common to the local context. A CNC-cut rail was used to position a shelf, which received laser-cut cardboard guides to help the builders (Figure 3).

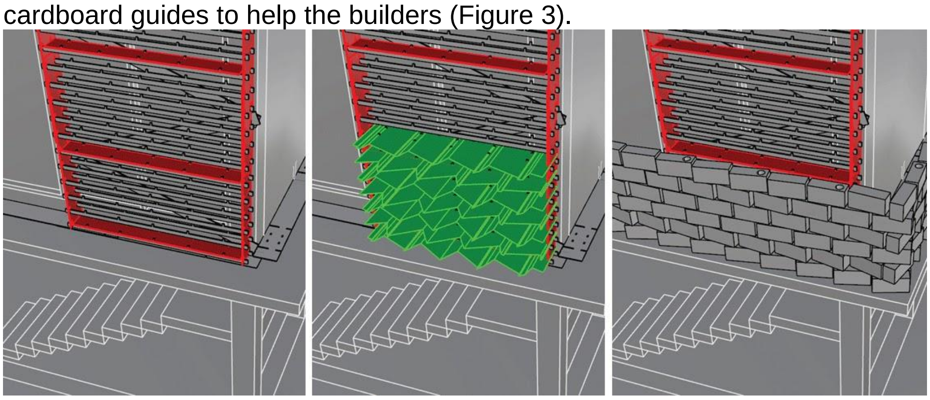

Figure 3. High-Low construction method used in the Coblogó building, with CNC-machined wood rails and rack and laser-cut cardboard guides (in green). Source: SUBdV, 2013.

In the Hyphas House, the use of any digital fabrication machinery or technical drawings was avoided. During the COVID pandemic, the authors realized that AR is a powerful didactic tool since students, most of the time, already own the necessary hardware: a computer and smartphones. Thus, the interest arose to test the feasibility of using AR with smartphones in designing and constructing a prototype.

Due to low cost and construction agility, cement blocks are generally used orthogonally. Technical drawings usually describe the position of such blocks without incorporating non-orthogonal angles, which would imply inaccuracy and higher labour costs. As previously shown, digital manufacturing technologies have made it possible to build designs in which each element is positioned at a specific angle. However, even with its increasing popularization, such machinery remains distant from the vast majority of construction sites.

Our proposal, in contrast, involves the use of equipment that is already present on construction sites but not yet used directly in construction: smartphones. Thus, the cost of implementing such technology is mainly in the training of workers. Therefore, it is possible to imagine its popularization to facilitate construction of complex shapes in a very short time and with low costs, which could be a transforming element of the built space, especially in Brazil, where, in the year 2020, there were about 242 million units of smartphones in use, totalling the mark of 1.1 devices per inhabitant (Meirelles, 2020).

A 7m x 12m grid was deployed over the construction site, then populated with QR codes at every 1 meter, which were used for referencing the location of smartphones in the physical space. The geometry of the prototype, initially developed by speculations in sketches and physical models, was later sophisticated and adapted by employing Rhinoceros and Grasshopper softwares. Together, these computer programs transmitted the information regarding the predicted position of each concrete block to the site, including both the location of each row of blocks and the aggregate material (biomass).

Duos of students with smartphones running the Fologram app (Jahn et al, 2018) placed each block on the worksite. With the smartphones demonstrating the relevant information for the row being constructed (Figure 4), these pairs of workers were alternated without detriment to understanding and continuity in fabrication. Due to some inaccuracies regarding the location marks pointed out through smartphones, after a few minutes of use, as discrepancies between the digital model and the physical prototype were observed, it was necessary to re-reference the position of the devices via QR codes.

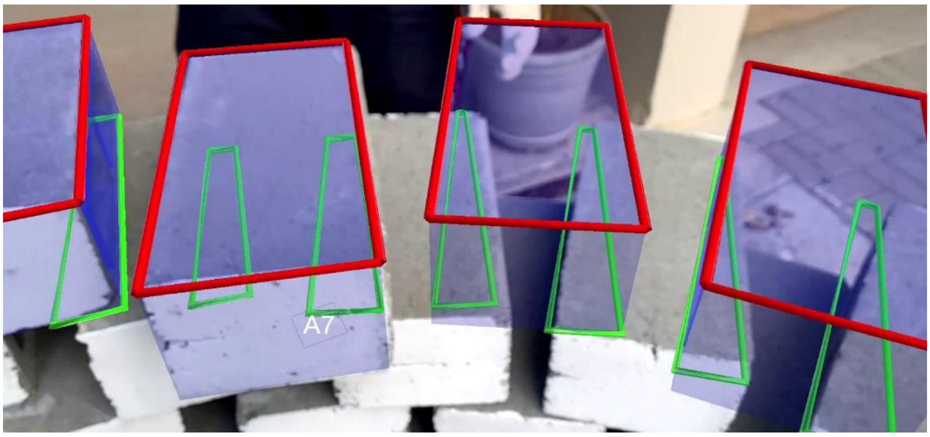

Figure 4. AR environment used for construction. In blue, the blocks to be laid. In red, the perimeter of their upper face. In green, the perimeter of the overlapping of the bottom row with the top row, where the biomass is applied. Source: Authors, 2021.

To facilitate understanding the overlay of the blocks on the digital model, only the most relevant information for each pair of users was displayed. At first, only the row being built was visualized. The geometry was represented in translucent blue, so that the physical block could be seen. In red lines, the perimeter of the top face of the block was used as a reference element for positioning. Finally, in green, the perimeter of the intersection between the blocks on each row was visualized for the location and proper application of the biomass.

2.2 Exhibition

In the Unity 3D development platform, an AR environment was created to allow visitors to access a virtual exhibition of concepts explored in the project, including panels with images, texts, videos and binaural audio (Rumsey, 2011). The goal was to enable the understanding of the design process and its physical execution. To complement the experience and point to the possibility of an architecture that does not respond only to the structural needs of the physical world, the AR exhibit incorporated a crowning structure that is only visible through smartphones (Figure 5).

An app was developed for the Android platform, using an adaptation of Peng, F. et al. (2017), which proposed an application for displaying content in a gallery through the Vuforia engine SDK.

Images (markers or targets) measuring 20cm x 20cm for recognition of the mobile application (tracking) were affixed on the physical object. The database of targets was fed by images with a predominance of idiosyncrasies, such as punctuations and specific well-defined borders, contrast, avoiding repetitive patterns, following aesthetic and technical criteria, evaluated by the

Vuforia online platform. The latter establishes scores from 1.0 to 5.0, according to the expected readability of each target, facilitating the development of solutions by anticipating decisions before generating the application for the smartphone.

In the Unity platform, 3D elements were compiled and associated with the images from the Vuforia database. The elements included: 3D models, institutional videos, photos of the construction process, and diagrams. The interaction of users with these elements happened automatically, from the reading of the cell phone camera, which recognized the targets positioned according to the proposed museographic narrative, activating the videos and animations of 3D elements.

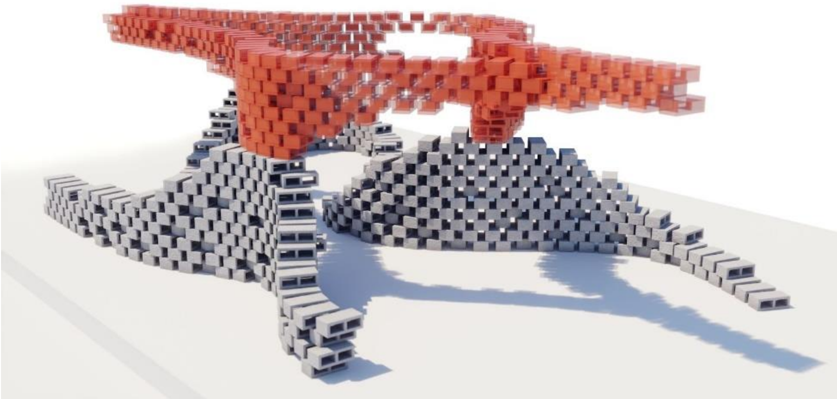

Figure 5 The virtual structure of the exhibit is superimposed on the physical elements. Source: Authors, 2021.

The software Figma was used for the development of the interface components in the virtual environment. Such interface allowed to structure the graphic content based on projects using smartphones, considered the primary device used by end-users. Therefore, design premises were addressed to make the contribution of each member in the development of the interface horizontal, as follows: 1. to meet Nielsen's Heuristics (1990) as criteria for better Human-Computer Interaction (HCI); 2. to scale the interface components to meet good User Interface (UI) practices according to the guidelines of Material Design (2021); 3. to structure the use of the interface elements and their readability considering the integration of the physical environment with the virtual environment.

The team initially familiarized themselves with the site and its pedestrian flows, seeking to understand and visualize how the contents present in the virtual environment could relate to the proposal of the physical space. In addition to previously developed components, digital prototypes were elaborated using site photos (Figure 6).

Figure 6. Digital prototypes with the simulation of the application of the interface (UI) components for Augmented Reality. Source: Authors, 2021.

Often in architecture and design, the algorithm implemented in the design process is not shared in the description of the methodology (Digiandomenico, 2019). It is common to encounter publications in the field that offer only the graphic representation of the algorithms with little readability. This condition discourages verification, replicability, and process improvement in the scientific arena. To mitigate the problem, a repository was created where the algorithms developed in this research are made available (accessible at: https://github.com/TecnologiasdoDesign/Casa-Hifa).

3 Results

The artefact (Figure 7) demonstrated that using AR in the building phase is feasible without construction drawings. However, at the current stage of smartphone self-referencing technology, our experience confirmed a tolerance of precision (ranging from 0.1 to 3 cm) in the location of the blocks. The construction itself took two afternoons, with three pairs working on laying the blocks simultaneously.

An important aspect was the use of biomass instead of the usual mortar, a product that is already available with the correct mixture. The geometry of its packaging ensures the tapering of the material, which facilitates its application from the guide shown in AR. In this way, the finish is more elegant, and material waste is avoided.

In the case of the virtual exhibit (Figure 8), the AR implemented in the integration between physically and digitally constructed projects resulted in a valuable resource for the presentation and navigation of visitors in the exhibition of the architectural artefact. However, factors such as sunstroke and visual pollution were challenges that compromised, to some extent, the execution: due to the glare effect, the targets exposed to the sun were captured by the cameras with some difficulty; in some occasions, the mapping of the targets was also compromised by backlighting; and, even with the effective reading of the targets, when moving away from the reference images, the user experienced registration failures. As for the latter, the juxtaposition of the 3D visual elements lost congruence with their spatiality analogous to the physical environment, given the interference of the structure itself and the movement of other people between the camera and the targets.

Two levels of perception are pointed out regarding the involvement of the end-user and the possibilities of interactions with the Hyphae House project. The first is physical, tangible, and manipulable when considering the execution practices. The second, on the other hand, is dedicated to the virtual environment, intangible and resilient. However, both are intertwined and capable of interacting and communicating. Thus, regarding the Interaction Design, the project is structured following Saffer (2010) because its nature is contextual and solves problems under particular circumstances and with available materials.

Therefore, it is possible to state that the proposal follows the three schools of thought in Interaction Design. The use of new digital technologies promotes positive experiences (The Technology-Centered View) by allowing for feedback in the digital environment (AR); by helping users to enter in other layers of space perception, and by promoting site mobility and engagement in experimentation behaviours (The Behaviorist View).

Finally, the project's social layer also becomes relevant (The Social Interaction Design View) by proposing, in a comprehensive way, interactions between people, physical and virtual objects, either through simple tasks, like sitting and talking, or by motivating the discovery of contents through AR.

4 Discussion

The prototype demonstrates that AR challenges the most common activity of the architect: the production of printed construction drawings (Carpo, 2011). Several authors have already pointed out the obsolescence of this action (Kolarevic, 2003), usually linking it to the introduction of robotics on the construction site in the future. Alternatively, our experience demonstrates in the present the feasibility of building complex forms through smartphones and low-cost software without such drawings.

Since their conception, computers have become ever closer to our bodies. Once huge machines occupying entire floors, serving teams of users, nowadays, with the introduction of personal computers, they have become desktop machines. With the advent of smartphones, we have become accustomed to having a computer in our pockets all day long, and it is even common to sleep next to our devices.

At the same time, this miniaturization and popularization of devices have transformed the way we work in almost all professions. However, due to the way we interact with computers, which are often delicate and generally require the exclusive dedication of our hands to interact with the mouse, keyboards, and touch screens, some professions have not been directly affected by this process. Surgeons and construction workers, for example, cannot interact in the usual way we handle such devices.

The focus of our work was the use of smartphones with AR on the construction site. However, we believe it is appropriate to speculate about the popularization of a new type of digital device. With the advent of AR goggles, we can identify two advances: first, computers are coming closer to us, out of our pockets and into our heads. Secondly, we can interact with them through gestures that define what we are seeing, allowing a new wave of professions to be transformed.

On the construction site, specifically, we see the possibility of visualizing information from several layers of the 3D model in an specific site and in a 1:1 scale. Such visualization can facilitate the understanding of the project among various actors, allowing the construction to be made possible without the need to interface with physical technical drawings. The multiple complementary projects that are part of the construction can also be visualized in loco, expanding our proposal, which focuses on the laying of masonry elements.

Figure 7. Prototype of the Hyphae House. Source: Authors, 2021.

Figure 8. AR exhibit the explanatory content of the design process of the Hyphas House. Source: Authors, 2021.

References

Norman, F. (2001) Towards a Paperless Studio - Reinventing the Discourse - How Digital Tools Help Bridge and Transform Research, Education and Practice in

Architecture in Proceedings of the Twenty First Annual Conference of the Association for Computer-Aided Design in Architecture (11-14 October 2001, pp. 336-343)

Gruber, P. & Imhof, B. (2017) Patterns of Growth—Biomimetics and Architectural Design in Buildings 7 (no. 2: 32)

Henriques, G. C., & Bueno, E. & Lenz, D. & Sardenberg, V. (2019) Generative Systems:Intertwining Physical, Digital and Biological Processes, a case study in Architecture in the Age of the 4th Industrial Revolution - Proceedings of the 37th eCAADe and 23rd SIGraDi Conference (Volume 1,11-13, pp. 25-34)

Tiffin, J. & Terashima, N. (2001). Hyperreality: Paradigm for The Third Millenium. Psychology Press, 2001

Locatelli, D. & de Paula, A & Omena, T. H. & Lara, A. - High-Low as expression of the Brazilian digital fabrication in SIGraDi 2018 [Proceedings of the 22nd Conference of the Iberoamerican Society of Digital Graphics pp. 718-723

Retsin, G (2019). Toward Discrete Architecture: Automation Takes Command in ACADIA 19:UBIQUITY AND AUTONOMY) pp. 532-541

Meirelles, F. (2020). 31ª Pesquisa Anual do FGVcia: Uso da TI nas Empresas. Disponível em: https://eaesp.fgv.br/sites/eaesp.fgv.br/files/u68/fgvcia2021pesti-relatorio.pdf

Jahn, G. & Newnham, C. & van de Berg, N. & Beanland, M. (2018) Making in Mixed Reality. Holographic Design, Fabrication, Assembly and Analysis of Woven Steel Structures. In Proceedings of the 38th Annual Conference of the Association for Computer Aided Design in Architecture (Pp. 88-97) Mexico City

Rumsey, F (2011). Whose Head Is it Anyway? Optimizing Binaural Audio in J. Audio Eng. Soc (vol. 59, no. 9, pp. 672-675)

Peng, F. & Zhai, J. (2017). A mobile augmented reality system for exhibition hall based on Vuforia in 2nd International Conference on Image, Vision and Computing (ICIVC). pp. 1049-1052, doi: 10.1109/ICIVC.2017.7984714.

Nielsen, J. & Molich, R. (1990). Heuristic evaluation of user interfaces in Proc. ACM CHI'90 Conf. (Seattle, WA, 1-5 April), 249-256.

Material Design (2021), Plataforma oficial da Google com diretrizes e boas práticas para o desenvolvimento de interfaces para Android. Disponível em: https://material.io/

Digiandomenico, D. (2019). Otimização de Projeto Orientado ao Desempenho em Arquitetura. Dissertação - Instituto de Arquitetura e Urbanismo, Universidade de São Paulo. pp. 84-85.

Saffer, D. Designing for Interaction: Creating Innovative Applications and Devices. New Riders: 2010.

Carpo, M. (2011) The Alphabet and the Algorithm (1st. ed.). The MIT Press.

Kolarevic, M. (2003) Information Master Builders in Kolarevic, M. Architecture in the Digital Age: Design and Manufacturing.