Postdigital Natures

Digital-material hybrids for robotic 3D printing of architectural elements

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Since what is often referred to as the 'digital revolution' in architecture, novel materials and digital tools have significantly altered architectural ecologies. The paper compares two case study projects as part of ongoing research. Examining overlaps between the natural, the virtual, and the built environments, it explores a variety of overlaps, continuities, and interfaces. Each project operates on the threshold of what is conventionally considered the 'natural' and the 'artificial' in material, shape, and experience contexts. Informed by theory, the projects establish nuanced interfaces between the digital and the material. Both projects were fabricated using robotic 3D printing with a variety of materials. The paper describes and compares them concerning sustainability and provides an overview of the different spatial concepts of the two projects.

Keywords: *Postdigital Architecture, Robotic 3D Printing, Sustainable Materials, Project, Hybrid Environments.*

INTRODUCTION

Climate change and global warming pressure architects, designers, and the building industry to operate more sustainably. While it is crucial to make existing processes more efficient, ecological, and sustainable new technologies and materials must also be explored. Besides new technological solutions, this also requires cultural adaptation. Architecture significantly impacts the organisation and design of urban natural environments. At the very latest, since the increasing digitalisation of our everyday life, architecture must engage with virtual environments too. Responding to those observations, the work presented here simultaneously engages with built, natural, and virtual environments. The research attempts to develop holistic design strategies that explore intricate forms while aiming to reduce the (usually associated) ecological footprint. Robotic 3D printing is a suitable strategy for developing such techniques. For this paper, the authors evaluated 3D printing as a construction method by reviewing its role in two projects. They are postdigital prototypes and lay on the threshold of virtual and real environments, sustainable design, digital technology, and media.

The Anthropocene

Our current time is increasingly described as the Anthropocene. It is a geological epoch defined by the effects of human activity. It has first been coined by Crutzen (2002) and its beginning is widely accepted to be the latter part of the 18th century. While there remains some debate about this exact date, it can be more generally defined as the moment when humans started to dominate the planet and long-lastingly alter its atmos-, geo-, and biospheres. (Klingan et al, 2015) In the context of this research, the Anthropocene is seen as an opportunity which allows architects to rethink established dichotomies. Blok (2017) described it as a 'radical opportunity' that allows us to rethink the demarcations between 'nature-technology' and 'nature-culture'.

'Sustainability'

Sustainability is broadly defined as a trifold of 'social, economic and environment'. (Purvis and Robinson, 2019, p. 681) The presented approach aims to sustainably 3D print and, therefore, to address item 12 of the UN's SDGs. In particular, item 12.5: to recycle plastics and 'substantially reduce waste generation through prevention, reduction, recycling and reuse'. (United Nations)

Traits of postdigital architecture

Twenty-five years ago, Negroponte (1998) announced that 'the Digital Revolution is over'. Throughout the past decade, postdigital research has emerged as a discipline (Andersen, Cox, & Papadopoulos, 2014). The postdigital is concerned with aesthetics (Andrew, 2002; Berry and Dieter, 2015; Cascone, 2000; Contreras-Koterbay and Mirocha, 2016; Hodgson, 2019) as well as with ways we design and think in an age of mass media and a myriad of new technologies (Ayala, 2013; Coyne, 2018; Kargl et al, 2019; Openshaw, 2015). In the context of architecture, two opposing strands can be observed. One, labelled 'quitters' by Carpo (2018), focuses on a mainly representational paradigm of collages without shading and aesthetics that are reactionary to digital architecture's topological complexity. The other strand embraces those digital tools and aesthetics, builds on them, and further develops paradigms of complexity, formal exuberance, and technological fetishisation.

The two projects presented in this paper identify as part of the second strand – as a continuation of the digital. Their key traits are advanced digital fabrication techniques, mixed reality experiences, notions of sustainability and ecology, and haptic experiences of digital realities.

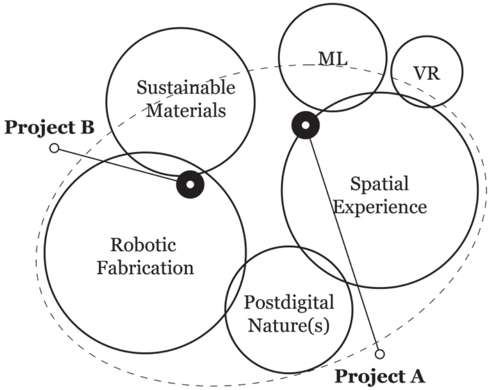


Figure 1
The weighting of project design foci of the two case study projects A and B

Hybrids

Digital architecture has often been characterised as homogeneous, smooth, curvilinear, and unarticulated. However, such digital surfaces are a blank canvas to be articulated, decorated, and defined. The traces on surfaces resulting from digital fabrication techniques can be seen as an ornament (Lynn, 2004). In the context of the work presented in this paper, the resulting forms are digital-material hybrids. Domeisen (2008) argues that ornament per se is the realm of hybrids. With this hybrid nature in mind, the paper asks how such digital-material hybrids can be physically and virtually designed.

METHODS

It is part of this research to investigate sustainability objectives, postdigital architecture traits, and hybridity, alongside discussing two case study projects: Project A and B (Figures 1 and 8). The two projects are analysed concerning technical limitations, and their key design principles are outlined, created, and exhibited in two consecutive years at the Ars Electronica Festival 2022 and 2023. The two projects - here differentiated as A and B for practical reasons - share certain aspects but differ in others. Both were fabricated using robotic 3D printing. While project A mainly investigates the design technique and method for MR environments, including haptic surfaces, project B focuses on creating a more sustainable environment and postdigital material ecologies. Both projects were designed and fabricated by the authors. The authors refer to the Acknowledgements at the end of this paper for a list of all involved parties. Interpreted sequentially, one builds upon the other, and certain aesthetic and methodic aspects are refined. The core of this paper focuses on the hybrid use of digital technologies and physical prototyping. Both projects document applied research into different sustainable materials for robotic 3D printing. They range from recycled to biomaterials, and reusable materials.

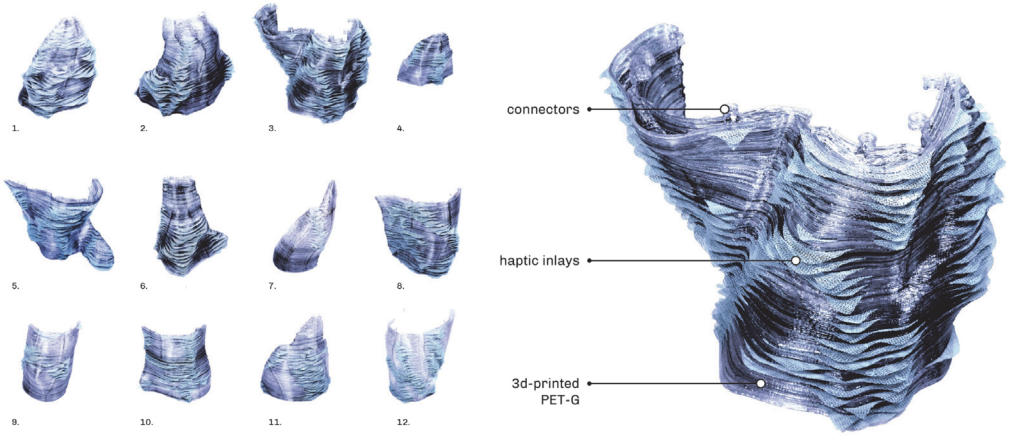


Figure 2
Overview of project A's 3D printed parts (PETG) with haptic inlays (silicone)

Project A – 'Triopic Spectacle'

Project A consisted of three key aspects—a central structure around a tree in a park. The tree had been 3D scanned using Lidar. It hosted a modular 3D-printed structure. The structure's shape was derived from an ML process based on acanthus leaves. The morphology played with the history of natural, ornamental motifs as part of the architecture (Figure 2).

Project B – 'Postdigital Natures'

Project B was a large-scale, robotically 3D-printed 1:1 installation made of recycled plastic and other bespoke biodegradable materials. It proposed artificial-natural, physical-virtual, technological-botanical hybridity as a metaphor for a future vision of a more intricate rapport between architecture and nature in the Anthropocene. It did this by exploring ambiguous overlaps and interfaces between the natural, the virtual, and the built environments.

RESULTS

The following paragraphs describe a series of key techniques consistently deployed for both projects. They include robotic 3D printing of various materials, the design of both virtual and physical, immersive environments, the use of machine learning to create artificial natures as well as for initial design studies,

Figure 3
Project A, titled '*Triopic Spectacle*' in Linz, 2021

and a design focus on haptic aspects of the experience of architectural spaces.

Robotic 3D-printing

Robotic 3D printing of various materials as a fabrication technique for large-scale architectural installations was explored. Based on previous experiences in this field by the authors and affiliated researchers, two materials were chosen for the main components of each installation. In the case of project A, it was transparent PETG (Figure 3) and in the second case, recycled PET (Figure 4). While A relied on a single material, B also used other, more sustainable, 3D-printed materials. While describing the details of the digital fabrication processes is beyond the scope of this paper, it is important to explain why this technique was chosen. 3D printing with a 6-axis robotic system allows each part to be different but also provides more flexibility in generating the tool path choreography, the heights of the printed layers, and the travelling speed of the printhead. Furthermore, the degree of freedom concerning morphology is great, and the process is scalable.

Haptic experience

Two sets of haptic experiences were designed for the projects. Both aimed to enhance the experience by providing intricate and soft textures to the hard 3D-printed surfaces.

Soft inlays. To enhance the haptic experience in project A, soft silicone inlays were integrated into the 3D prints. This multi-material strategy created textured surfaces that mimicked the intricate digital surfaces of the VR experience. This fabrication technique is novel and was developed specifically for this project. Each silicone fin corresponds to a digital one. The silicone was CNC cut and manually positioned during the 3D printing process. Using a force-sensitive *Universal Robot (UR)* industrial robot allowed safe human-robot collaboration. Visually, the inlays remind of tree mushrooms and add another layer of mimicry to the structure. Conceptually, the soft tissues formed hybrid feedback points between the virtual and real environments (Figure 5).

Figure 4
Project B, titled 'Postdigtal Natues of Planet B', in Linz, 2022

Figure 5
Haptic inlays (close up) of project A, Triopic Spectacle

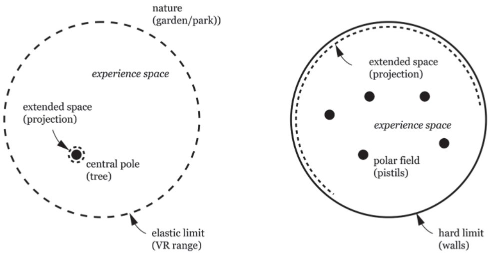
Soft coating. For project B, glass wax was applied to the hard PET surfaces to create a thin, transparent, and soft haptic layer. This layer creates the sensation of wet, organic tissue when touched, which is perceived with awe and disgust. In the case of project B, this haptic layer was allied after 3D printing. In the case of project A, the tactile experience was integrated into the printing process. (Figure 6)

Eccentric, immersive environments

The projects were intertwined with dynamic and interactive virtual environments, recognising the immersive tangibility of virtual realms in our times (Figure 7).

Figure 6
Soft coating (close up) of project B, *Postdigital Natures*

Figure 7
Spatial conditions and relationships of each case study project



In both cases, the fabricated material elements were central pieces around the experience. Whether this was mainly in the virtual realm, as in project A or the physical world, as in project B, is irrelevant to this paper; this surrounding field provided a certain eccentricity around central nodes in both cases. The constraints were either technological, e.g., the maximum range of a VR headset, or spatial, e.g., the size of a room. In the case of project, A, the physical structure was at the centre of the experience. All other virtual aspects were centred around this node. The natural part of the site, the tree, acted as a structural host for the artificial intervention onto which digital content was projected. This central point formed the visual and haptic core of the MR experience. In the case of project B, the physical elements were arranged as a field. The projections of an ML-generated jungle were mapped onto the surrounding perimeter walls, which acted as hard limits. Here, the room was not extended using VR, but the rigid walls became immaterial, extending the space beyond the datum through projections. While project B was contained and only took place on-site, project A operated on three levels. They were the physical experience on-site, the virtual experiences using VR headsets, and the participatory online broadcast via Mozilla:hubs (Mozilla, 2021).

Sustainable materials for 3D-printing

Project B had a more extensive scope in terms of scale and area. It also was indoors, while project A was outdoors (Figure 3 and 4). It aimed to focus on more sustainable materials for 3D printing for ecological reasons. Four material and printing strategies were pursued, helping to discover a broad field of possibilities and to compare their respective potentials. The objective was to understand the interplay between production, material properties, and material origin. The four approaches intentionally cover a spectrum of different sustainability concepts.

- Recycled materials (PET)
- Traditional, pure material (clay, ceramics)
- Bioplastics
- 100% biodegradable material

The choice of materials led to design paradigms that respond to the form-finding capacities and limitations of 3D printing architectural fragments. This basic research on technology and design intelligence enabled us to focus on materials that produce significantly fewer carbon emissions. Hence, they result in a lower environmental impact.

In project B, the main elements of the installation ('pistilis') were fabricated from **recycled PET** (Polyethylene terephthalate). The material is a petroleum-based product that has already undergone recycling processes.

PET is a popular material for the beverage packaging industry due to its material properties like light weight, resistance to breakage and high level of resilience. PET is the most common thermoplastic polymer used in various applications, usually by injection moulding. However, the raw material was processed through material extrusion for the project.

Two particularities of the printing process were integrated. First is the gradual inclination of the layer corresponding to the generative edges of the design. Second, the print speeds were locally varied to generate a porous surface (Mohite et al, 2019). The resulting glitch in the print path opens up the surface. This mutual feedback between the digital model and the physical (material and process) hybridise to a particular design paradigm eccentric of the scope of the *Digital* and thus could be understood as a *postdigital* trait.

Of course, experimental 3D printing with materials not intended for 3D printing comes with challenges. Compared to other projects printed with PET-G or PLA - we remarked that PET is brittler - has a lower impact resistance, a higher shrinkage ratio and results in spontaneous cracking, mainly between the printed layers. Furthermore, PET is a lot more hygroscopic, which absorbs moisture more quickly.

In the project's landscape surrounding the pistils, 21 objects made of clay are distributed. Clay is one of human history's oldest art, utility and building materials and is a **100% natural material**. The project demonstrates the high precision, scalability and detailed surface articulation that 3D printing breathes new aesthetic and performative life into this traditional material. In addition, the targeted application of glazes allows the material's properties to be further specified. The product used has a white to light cream colour after firing.

Considering the shrinkage of clay, the digital model is scaled up. Previous research by the authors has shown that approximately 6% of the volume shrinks after drying and a further 3-7% during firing. Depending on the geometric typology, shrinkage leads to stresses and cracks in the material and shape deformation. Furthermore, local path deviations resulted in glitches in the surface which had been utilised as a design potential to articulate the surface of the objects.

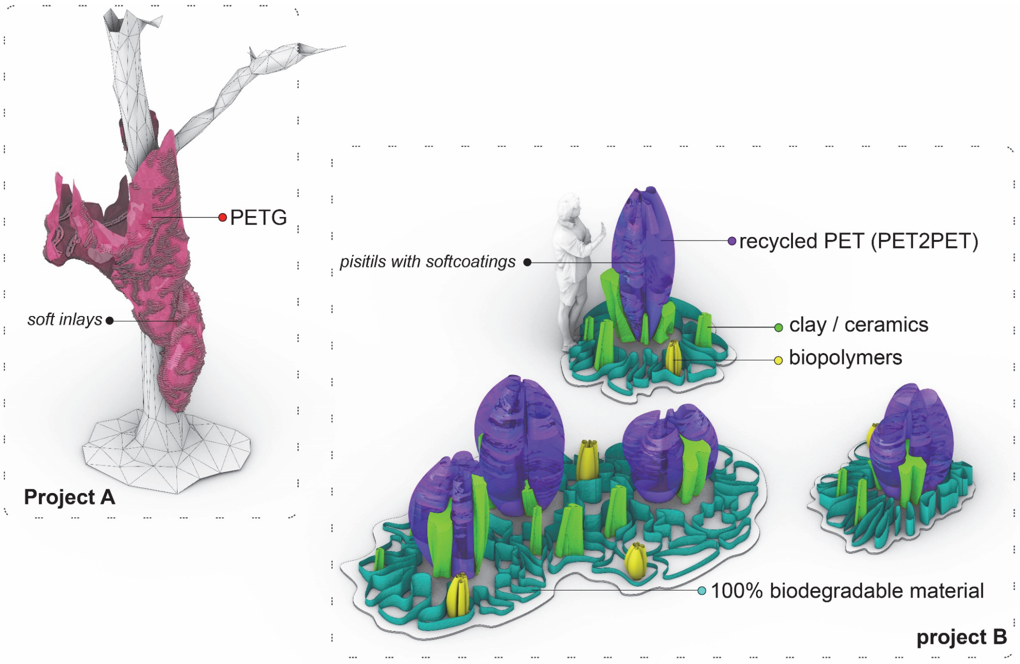
In terms of a postdigital design strategy, the hybridisation of the digital design process and the mutual feedback to the physical process is a shift from a former digital imperative.

Like the clay prints, seven objects were printed with **biopolymers**. The printing device of the PET printer was slightly adapted for the purpose.

Biopolymers are a compromise between natural materials and plastics. The advantage of these materials for 3D printing derives from the availability and industrialised high-quality production meant for 3D printing.

Biopolymers are plastics made from biomass. Hydrocarbons made by fermentation of biomass (corn, soya, sugarcane) can be polymerised to make bio-polyethene (PE) and bio-polypropylene (PP) (Ashby, 2021). These so-called *dropin* biopolymers have properties identical to their oil-based equivalents, which they directly replace. Other biopolymers, such as polylactide (PLA) and polyhydroxyalkanoate (PHA), have a biological origin but require specific processing methods. The materials used in the project were *Arboblend V3 NF15* and *UPM Formi 3D*. Both materials consist mainly of PLA and are filled with natural reinforcing fibres of around 20% and organic additives. Wood-based cellulose fibres give extra stability and strength and provide wood-like post-processing possibilities.

Figure 8
Overview of projects A and B, parts, and materials



The pistils and the clay objects are embedded in a landscape of 3D-printed cells made from **100% biodegradable material** (Figure 8). The landscape covers an area of 12 m^2. Biodegradable materials are typically composed of renewable natural raw materials. The goal to 3D print 100% biodegradable materials is the most experimental bottom-up approach yet since this has been researched by a few researchers only, to name Roche (2006), Oxman (2010), Armstrong (2019), and Vasiliki et al (2022). The mixture that was used for the project consisted of Wood (as chips or flour), water, acetic acid, starch, glycerine (E422), and methylcellulose (E461). Water solubility, gel-like consistency and final strength are key properties of these 3D printable mixtures.

A second iteration of a low-cost printing extruder for pasty materials was developed for the project. Attached to a *Cobot UR-10e,* the printing setup could print elements in various sizes and shapes. Controlling the material behaviour was challenging, and different adaptations of the geometric typology had to be made to avoid collapsing the printed objects.

These investigations are the first step to achieving similar design results as mentioned in the previous material approaches. Still, the development follows the hybridisation of digital and physical material.

DISCUSSION

Both projects engage with the dialectics of *artificial* and *natural* in architecture. They do this on materials, design processes, and environmental concerns. The resulting postdigital experiences suggest new forms of engagement between the built and the natural environment. While project A focuses on an autopoietic interactive narrative, the potential of transmedia and the permeability between the physical and the virtual. Project B focuses on a metaphorical narrative and the technological stance on developing sustainable materials and fabrication (Figure 8).

In the bigger picture, both projects showcase essential aspects of the shifts in digital architecture. On a descriptive level of the *Digital* and in consideration of the seminal works of Carpo, Lynn, Cache and Spuybroek, the projects align with their concepts like 'multiplicity' (Lynn, 1999, p. 20), the 'objectile' (Cache et al, 1995, p. 87), fuzziness, 'excessive resolution' (Carpo, 2016, p. 80), and 'ornamentation' (Spuybroek, 2011, p. 89). On the other hand, the aspects of transmediality as intertwined realms of reality fundamentally differ from the purely *Digital* notion; also, the non-authorial approach towards materials and fabrication process is another difference which is not considered by digital imperatives of the before mentioned.

In detail, the fabrication strategies in the projects show a clear stance towards more sustainability in architecture that is not capitalised in the *Digital* at all. The projects also demonstrate, with their narratives, recognising the Anthropocene as a task to meet nature in all its nuances halfway, linking to the historical discussions of biomimicry and the opposing abstraction. For instance, Carpo's (2017) critique of the streamlined aesthetic of the 90s could be understood as a critique of abstraction. However, the projects show that aesthetic traits cannot be associated with a specific technological paradigm since the streamlined objects of A and B derive the morphology from the digital printing technology and the properties of the materials.

Thus, the historiographic paradigms of Digital Design may no longer apply to all extents. Building on past developments, the traits of the concepts like the integration of the virtual, the natural and the physical could be described as fulgurations of *Digital Design* towards a postdigital notion.

Critical reflections

Both projects explored postdigital architectural experiences within the limiting constraints of temporary installations. For a more comprehensive analysis of the experiences, an evaluation strategy should be deployed in the future, potentially helping to understand better and map individual users' different spatial experiences. Similarly, the research on sustainable materials for 3D printing requires further research concerning actual carbon footprints and material recycling. Furthermore, both projects relied heavily on quasi-natural aspects that mimic nature rather than directly incorporating natural agents such as flora or fauna through bio-integration.

Future works

When reviewing the results, it becomes clear that a third project is required. Since buildings are (still) predominantly static and long-lasting structures, those aspects must be investigated in the future. If buildings are to become more heterogeneous, multi-species, multi-media, and diverse environments, those notions of static vs. dynamic must be overcome. While this is, admittedly, easy using digital tools such as projections and VR headsets, future work must explore how this can be done with non-electronic means such as materials and living organisms.

CONCLUSION

This study aimed to shift the conversation by taking a dialectical approach to postdigital design, emphasising the importance of materiality, sustainability, circularity, and their integral role in the design process.

The relationships between the natural, the virtual, and the built environments are key to understanding architectural design in the Anthropocene. These aspects indicate the potential to develop concepts, tools, and processes to deliver appropriate actions to achieve the SDGs without compromising design quality. Quite the contrary, design intelligence in juxtaposition with materials, fabrication processes, and avoidance of production by virtual realms could lead to aesthetic results that even carry the meaning of a sustainable endeavour.

The two projects, designed and fabricated a year apart, document a change in focus from shape to material. While project A investigated the tangible interfaces between realms of virtuality, project B considered the material manifestation of digital design concepts in an ecological context.

Reconsidering *Digital Design* may indicate a pause or linearity in the history of digital developments in architecture. However, *Digital Design* continuously develops with various furcations. Indeed, as demonstrated in this paper and the case studies of projects A and B, past fulgurations changed digital design paradigms. Hence the notion of digital design is not outdated but could be altered in its continuation to a postdigital understanding of design.

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