Chapter 13
Democratising Tectonism: High Performance Geometry for Mass-Customisation of Virtual and Physical Spaces

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13.1 Democratising Impactful Digital Design and Construction

Architecture, like video games, movies, and music, is a technology-enabled cultural production. Architecture is not a product that is a direct outcome of technology. In other words, architects, engineers, and constructors use technological tools to realise ideas that are culturally and socially engaging. Games, the computer- generated movie industry and associated production pipelines have long understood this. Movie creators wield technological tools to tell socially and culturally engaging stories. Technical developers and the vast research industrial complex of the game and movie industry create the technological tools, not the movies. We ought to recognise this when applying software to architecture and construction.

Unlike the widely held belief in the Architecture Engineering and Construction (AEC) industry, problems in housing and other forms of socially driven and engaged urban development will not be solved by automation and vertically integrated project delivery alone. They could however be solved by democratising good design—creating the interactive design-assisting tools, incentivising user generated content, creating spatial pre-sets, adaptive components derived from high-performance (spatial & ecological) global best practice that is being demonstrated in the professionally generated content (PGC) developed by the bleeding edge architectural and engineering firms.

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In such a context, *Architectural Geometry* (Pottmann 2010) (AG) is a highly relevant design technology paradigm. AG focusses on the synthesis of shapes that guarantee structural and fabrication optimality. It is also closely aligned with and complementary to the development of robotic and digital fabrication (RDF). Further, in combining historical geometry-based methods of structural analysis, modern mathematics as used in computer graphics (CG) and computational technologies, the field is opening several rich shape-possibilities that are also economically viable—a new *Tectonism* (Schumacher 2014a). Design that is so digitally empowered is already proving to be significantly more effective in terms of spatial expressivity and user-experience (Schumacher 2014b), ecologically (Rippmann et al. 2018), preservation of building trades (Fallacara 2009) etc. Thus, the recent and rising popularity of AG is not surprising considering it has brought the principal stakeholders in the architectural design process—architects, engineers and fabricators, and their respective toolchains much closer together (Louth et al. 2017; Bhooshan et al. 2018a).

Architectural Geometry, Tectonism and the Metaverse

Cyberspaces are virtual spatial environments in which human-to-human communication can happen, over computer networks. Current photo-real, high fidelity and massively multiplayer online (MMO) video-game creation technologies combined with high-speed network and cloud technologies enable such cyberspaces to be 3-dimensional (3D), interaction-rich and socially and sensorially engaging. Thus, cyberspaces are 3D spatial, digital assets augmented with communication capabilities. They are accessible from a variety of commercial devices including desktop browsers, mobile apps, smart TVs etc. Together, these features of cyberspaces make them an integral part of the spatial-web technologies underpinning the so-called *Metaverse*—a rapidly expanding online, socio-economic market, enabling novel cultural, social, and business opportunities.

However, at the heart of this exciting and vast architectural opportunity lies a technological divergence. Architects are not aware of game-tech used to create spatial content for the metaverse. On the other hand, game and so-called level developers are not aware of architectural design—tectonic, spatial, user experience logics and their implications on the look and feel of spaces. Thus, often the architecture depicted in the metaverse is bland or comical.

The explosive opportunities for both new business and rapid testing and refinement of core competencies of design provide the incentive to align architectural design technologies with those in game production. Unlike the Building Information Modelling (BIM) paradigm that is dominant and widespread in the AEC industry, Architectural Geometry is much better aligned with geometry processing, computer aided shape design, user-experience analytics, and other computer graphic technologies (Bhooshan 2016a, b, 2017). Thus, AG and game-tech are very compatible in terms of the underlying technology, in the designer-friendly, interactive design ethos and in supporting the dramaturgical focus of the creators.

Architectural Geometry, Games, and Governance Technology

Geometry-based abstraction of complex structural and manufacturing phenomena is an integral feature of AG. This means that many of its core technologies are easily transported to non-expert computer aided design (CAD) platforms such as web browsers, web-services, and game platforms. Gaming platforms are increasingly considered for ‘gamified’ solutions that require social engagement, multi-stakeholder participation, and negotiation of trade-offs (Bhooshan and Vazquez 2020).

Governance for the built environment requires such solutions. However, it is typically the anti-thesis of participatory solutions involving centrally instituted policies and regulations related to real estate taxes and policies, zoning laws, infrastructure development plans etc. By contrast, the so-called Governance Technologies (Gov-tech) are a technological layer for enabling effective, decentralised, participatory governance—allocation of resources, decision-making, and delivery of services to inhabitants. The stack of such technologies including block-chain, Internet of Things, decentralised finance, and their combinations with game-engine based, user-centric, interactive 3D platforms are gaining significant momentum.

Together, such cyber-physical platforms couple the social, exploratory and network-effect benefits of online ‘metaverses’ and the effective resource utilisation of digital twin technologies. On the one hand, they provide a minimal risk, online environment for experimentation, incorporation of participatory wisdom of non-experts, expert knowledge systems, and stakeholder freedoms. On the other hand, they provide expedient and resource efficient physical realisation and operation. Cyber-physical architecture and urbanism empowers human betterment via effective resource utilisation. They are imminent, exciting, and critical to the future of our societies and their physical receptacles.

A Technological Thesis Borne from Practice and Collaboration

Zaha Hadid Architects (ZHA) have collaboratively evolved expertise and proprietary technologies at the intersection of spatial user-experience, interaction, and design with computational technologies of algorithmic 3D geometry creation, game3D & MMO, and user-analytics. Furthermore, ZHA has early-adopter, pilot project experience in developing user-experience focussed spatial designs, and in the preparation of corresponding high quality 3D assets that are compatible with video game engines that power the high fidelity metaverse. ZHA also has long-standing expertise in developing 3D spatial and architectural assets by adapting so-called Digital Content Creation (DCC) toolsets that are commonly used in the computer graphics, animation, and video game industries. In fact, ZHA spent close to two decades collaborating and learning to extend the CG and game-development technologies stack for architectural production. Recent cyberspace-design collaborations with Player Unknown’s Battlegrounds (PUBG), Kenny Schachter (NFTism) and Mytaverse

(Cyber-Liberland), validate these benefits of adapting game-tech (see Sect. 13.4). The following observations and a technological thesis follow from the experience and expertise accrued.

A so-called *Spatial Technology Stack* (STS), can robustly support the

– synthesis of high-performance shapes including structurally optimised geometry and its processing for robotic and digital fabrication (RDF) (Block et al. 2020; Block 2016);
– creation of environments that deliver novel, engaging and productive spatial user experiences (Schumacher 2014b)—both in the physical and virtual instantiations of architecture.

Stemming from the observations above is a technological thesis: *The spatial technology stack, compared to the current and dominant BIM-based architectural technologies, provides a powerful technological basis for engaging and responsible design, both online and on-land.*

We will argue, for the rest of the article, that STS is better aligned with

– The cultural production view of architecture and thus the core social and physical tasks of architecture.
– Spatial user-experience (UX) design and end-user ergonomics.
– Integrated design and construction and the ecological benefits thereof, including making them more widely available to the AEC industry.
– Game-tech powering the metaverse including so-called synthesis of performance optimised geometries, no-code or low-code platforms and application programming interface (API) requirements, collaborative technology development etc. This compatibility also enhances the potential to attract new talent into the AEC industry and to empower them to increase architectural experimentation via user-generated content (UGC).

13.2 Spatial Technology Stack

Spatial Technology Stack (STS) is the convergence of spatial design disciplines with computational technologies associated with architectural geometry (AG), computer graphics (CG) and gaming.

STS, which is congenial with Tectonism, incorporates and stylistically heightens the essential aspects of structure and fabrication in addition to increasingly encoding the social, ecological, and economic parameters into the shape modelling process. The recent advances and increasing popularity of AG have brought the principal stakeholders in the architectural design process—architects, engineers and fabricators, and their respective toolchains much closer together (Pottmann 2010; Panozzo et al. 2013; Prévost et al. 2013; Schwartzburg and Pauly 2013; Tamke 2015; Jiang et al. 2014; Michalatos and Payne 2016; Bhooshan et al. 2018b). This is true both in the early design phase and across the design to the physical production pipeline (see Sect. 13.3).

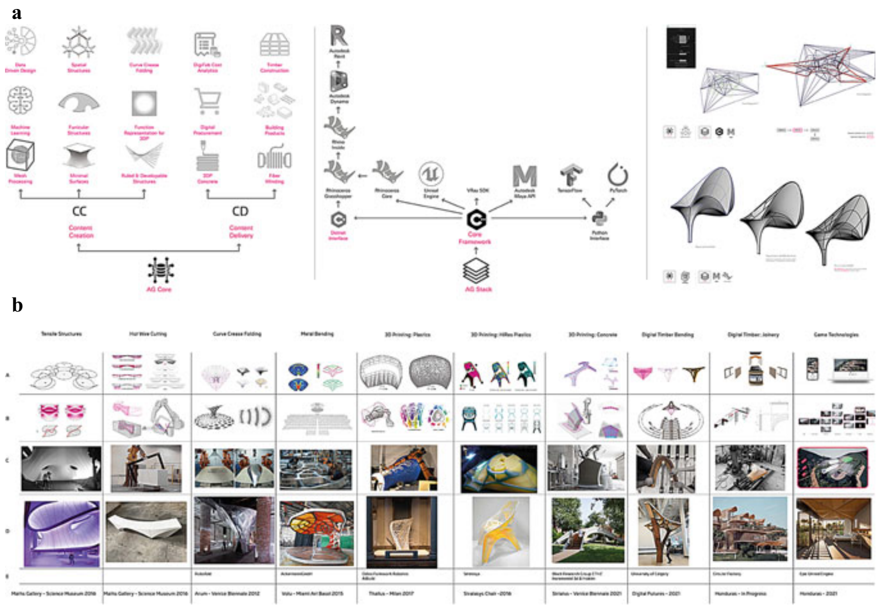

Fig. 13.1 **a** Development of technology stack to create toolsets, interoperability, and sand-box testing. **b** Digital and physical technology demonstrators

User Generated Content (UGC), typically used in the realm of journalism and social media, is disruptive as it empowers creative individual users with digital technologies (Lobato et al. 2012). In AEC, we believe STS in combination with curated professionally generated components will play a significant role in facilitating participatory practices and alleviate some of the critical constraints of only Professionally Generated Content (PGC) noted in Sect. 13.4. The Producers of PGC can thus turn "digitally empowered interactive audiences into value-generating co-producers" (Bruns 2007; Jenkins 2006). The recent developments in configurators, phygital spaces and metaverses further reinforce this trend (see Sect. 13.4) (Fig. 13.1).

13.3 Professionally Generated Content

The tech-stack and the interactive design environment (IDE) for Professionally Generated Content (PGC) inherits toolkits commonly found in the CG industry which enables the creation and manipulation of discrete representations of geometry—meshes, graphs, voxels—texture packing etc. Such discrete representations, though ubiquitous in the CG and animation industry, have hitherto not been as prevalent in architectural design. This is mostly due to the lack of appropriate creation and manipulation toolsets in popular Computer-Aided-Design (CAD) applications used by architects (Pottmann et al. 2006). Aided by recent developments in the application of discrete differential geometry to architectural design problems, the paradigm of AG favours discrete representation (Panozzo et al. 2013; Prévost et al. 2013; Schwartzburg and Pauly 2013; Tamke 2015; Jiang et al. 2014; Michalatos and Payne 2016; Bhooshan et al. 2018b). The Authors have invested more than 15 years in collaborating and learning to extend the CG and game development stack for IRL architecture. For further reading we point the reader to Louth et al. (2017; Bhooshan et al. 2015, 2018a, b, c, d, 2019; Bhooshan and Sayed 2011; Bhooshan 2016c; Reeves et al. 2016).

IDEs are valued as they facilitate the use of contemporary paradigms of edit and observe / interactive modelling (Prévost et al. 2013; Jiang et al. 2014; Rabinovich et al. 2018; Tang et al. 2014; Bhooshan et al. 2018c); exploration of static equilibrium shape design (Tang et al. 2014; Vouga et al. 2012; Block and Ochsendorf 2007; Akbarzadeh et al. 2015; Lee 2018); greater design control in the production and delivery stages (Louth et al. 2017; Bhooshan et al. 2018d) and provide a feedback loop between the various stages of the design workflow (Louth et al. 2017; Bhooshan et al. 2018a).

Benefits of Spatial Technology Stack

The following case studies illustrate the benefits of using STS in all phases of architectural projects—design, structural coordination, fabrication, and construction phases—as well as engaging the principal stakeholders of the projects.

Winton: The Mathematics Gallery at Science Museum, London

The design of the gallery, which welcomed more than a million visitors in the first six months and had increased dwell time in comparison to its predecessor, highlighted the benefits of considering rich spatial interaction-based user experience in the initial stages of design. Embedding analytics, associated UX metrics in an IDE, allowed for ease of iterating, and accommodating changes to the spatial layout if the objects, stories, or any other aspect of the curatorial vision were to change.

In addition, the IDE powered with integration of mathematical models, structural and fabrication constraints enabled:

- exploration of a wide variety of shapes in the constraint design space and negotiation of often disparate requirements—curatorial vision, ease of navigation, construction costs etc.
- exploration and iterative collaborative refinement of the fabric seams with the fabricator.
- effective workflow wherein the design could be updated and refined till the day of the production.

- customisation of each of the 14 benches to be unique, whilst still not compromising on the production time.

For more details regarding the project, we point the reader to Bhooshan (2016c) (Fig. 13.2).

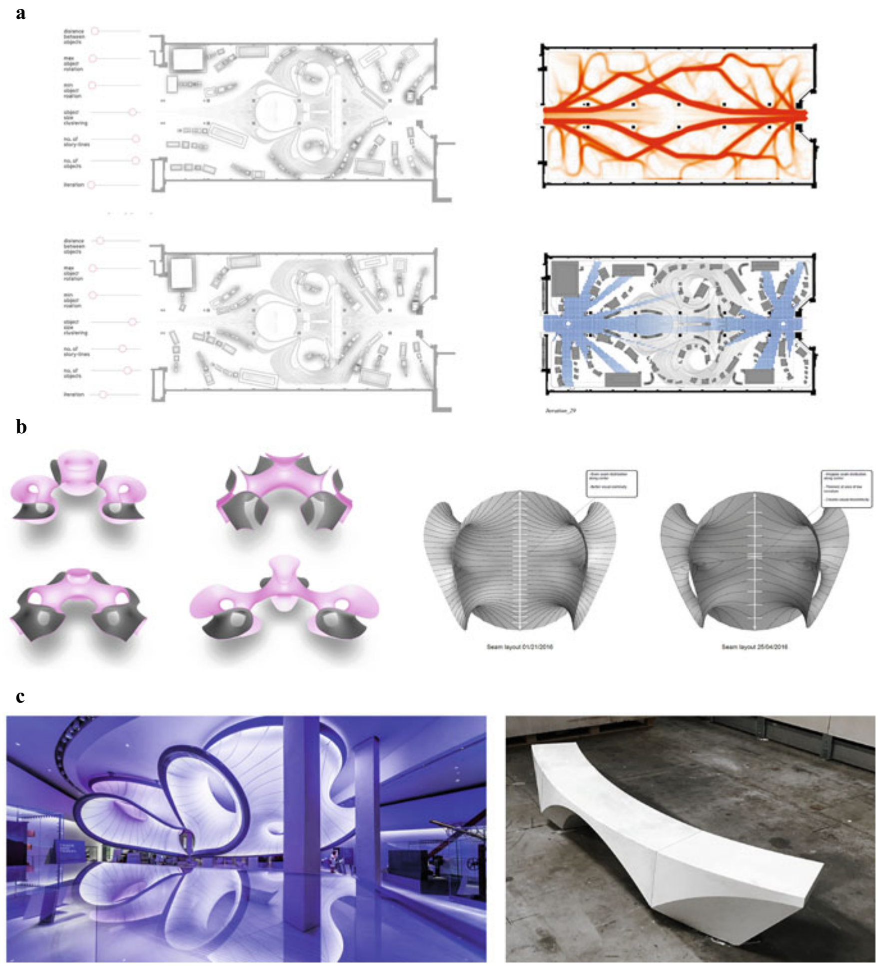

Fig. 13.2 **a** Winton: The Mathematics Gallery (a) Toolset for Parametric Object Layout, (b) Toolset for user parametrics and visual field analytics. **b** Winton: The Mathematics Gallery (a) Generative shape generation, (b) iterative seam pattern development of fabric pod. **c** Winton: The Mathematics Gallery (a) fabric pod, (b) cast, ultra-high-performance concrete benches

Striatus—3D Concrete Printed Masonry Bridge

Striatus is an arched, unreinforced masonry footbridge composed of 3D-printed concrete blocks assembled without mortar. The paradigm of strength through geometry coupled with precision placement of material only where needed using Robotic 3D printing, significantly reduced the environmental footprint of the bridge. Built without reinforcement and using dry assembly without binders, the bridge can be installed, dismantled, reassembled, and repurposed repeatedly; demonstrating how the three Rs of sustainability can be applied to concrete structures.

– Reduce: Lowering embodied emissions through structural geometry and additive manufacturing that minimises the consumption of resources and eliminates construction waste.

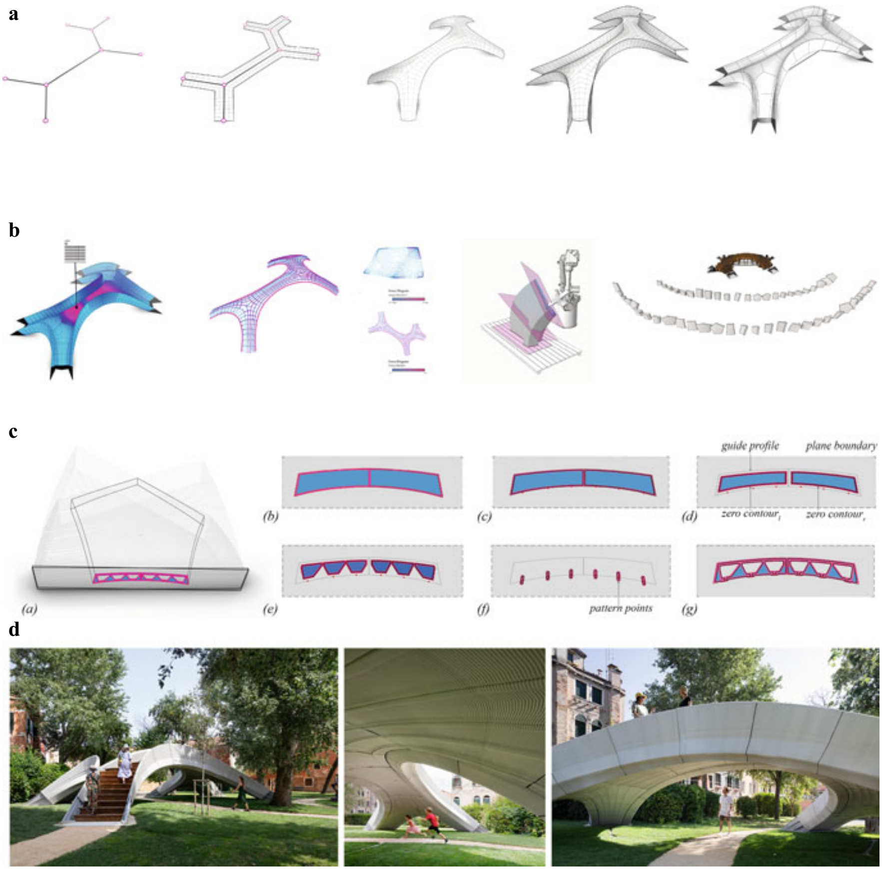

Fig. 13.3 **a** Striatus, geometry development sequence. **b** Striatus, workflow integration with structure, robotic fabrication and assembly. **c** Striatus, force aligned cross section and print path generation using sign distance fields. **d** Striatus, photographs of completed bridge

- Reuse: Improving circularity and longevity. Unlike conventional reinforced concrete structures, Striatus is designed to be dry assembled without any binder or glue, enabling the bridge to be dismantled and reused in other locations.
- Recycle: By ensuring varied materials are separated and separable, each component of Striatus can easily be recycled with minimal energy and cost.

The design-to-production (DTP) toolchain of the project developed using a mesh-based geometry-processing paradigm enabled for a collaborative and multi-authored design iteration and development. The use of JavaScript Object Notation (JSON) enabled lightweight and efficient transfer of 3D information with custom attributes between the various collaborators (Fig. 13.3). For more details regarding the project, we point the reader to Bhooshan et al. (2022a, 2022b).

Xi'an International Football Stadium

Set to be built in the Fengdong business district of Xi'an, one of the key design features of the stadium was the sheltering of the spectator seating with the lightweight large span roof. The shape design of the dual layer cable-net roof negotiates multiple objective constraints of spectator shading, natural light requirements for grass growth on the pitch, uniform force distribution, number, and length of cables. The integration of geometry-based form finding tools (Block and Ochsendorf 2007; Schek 1974) in the IDE during the initial stages of design enabled testing of multiple topologies and collaborative discussion and negotiation with the structural engineers for reduction of structural elements and depth especially at the oculus. The project highlights maturation of ST and its adoption in large scale creation and coordination of architectural packages—facades and envelopes, structure etc.—through efficient transfer of data streams using Geometry Method Statement (GMS) and associated parametric methods (Fig. 13.4).

Dnipro Metro Stations

The design of the station entrance shell canopies at Dnipro explored procedural generation of shapes from input graphs, which were adapted to the urban site conditions, entrance access, spatial, navigational, and other design constraints. The IDE helped design shapes which negotiated multi objectives of form-found surfaces with that of being developable for manufacture with flat sheet material. A streamlined parametric workflow between the various collaborators—architects, structural engineers, fabricators—enabled the delivery of all the station canopies—three stations, six canopies—concurrently and in a resource effective manner.

In summary, PGC powered by STS, is proving to be significantly more effective in terms of spatial expression and interaction rich user experience; ecologically—high performance with less material; efficient and lightweight exchange of data

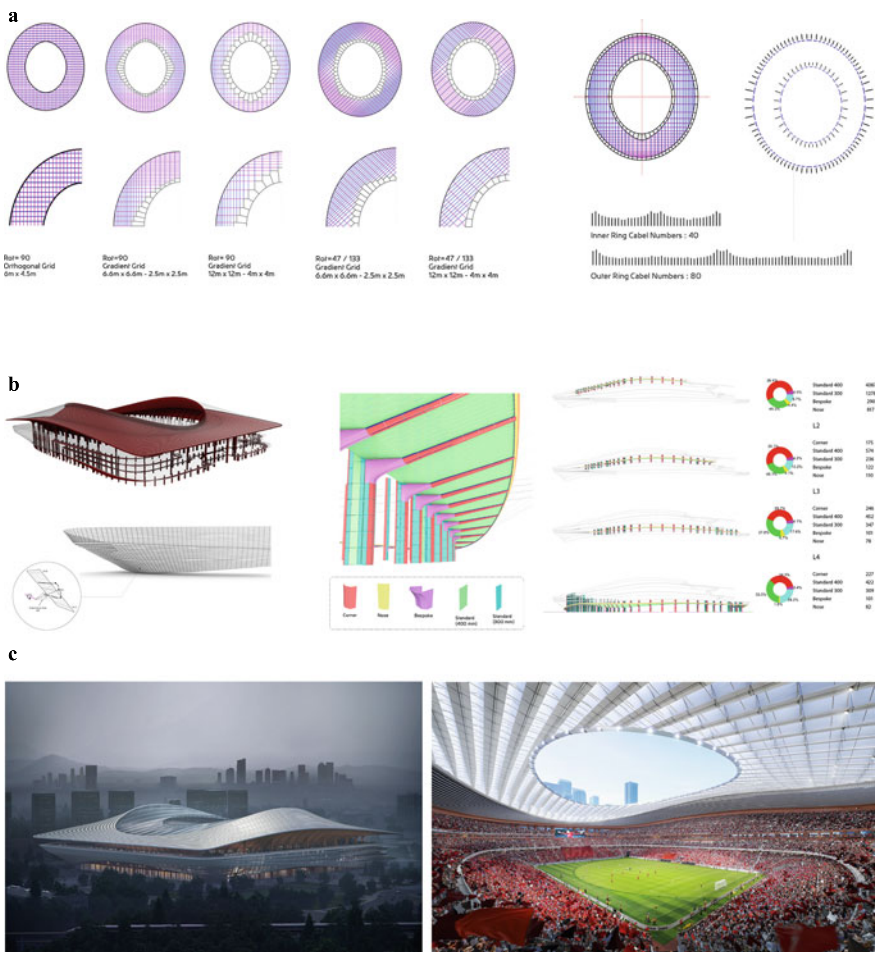

Fig. 13.4 **a** X'ian football stadium, CableNet topological iteration and optimisation. **b** Xian facade optimisation and geometry method statement. **c** X'ian football stadium, Exterior and Interior cable net and bowl renders

amongst collaborators and amenable with game technologies and user engagement with professionally curated content (See Sect. 13.4) (Fig. 13.5).

Critical Constraints of Professionally Generated Content

PGC, despite its design benefits noted in Sect. Benefits of Spatial Technology Stack, is currently expensive to make digitally as the creation of such PGC involves acquisition of considerable digital skills and requires investment in the development of the

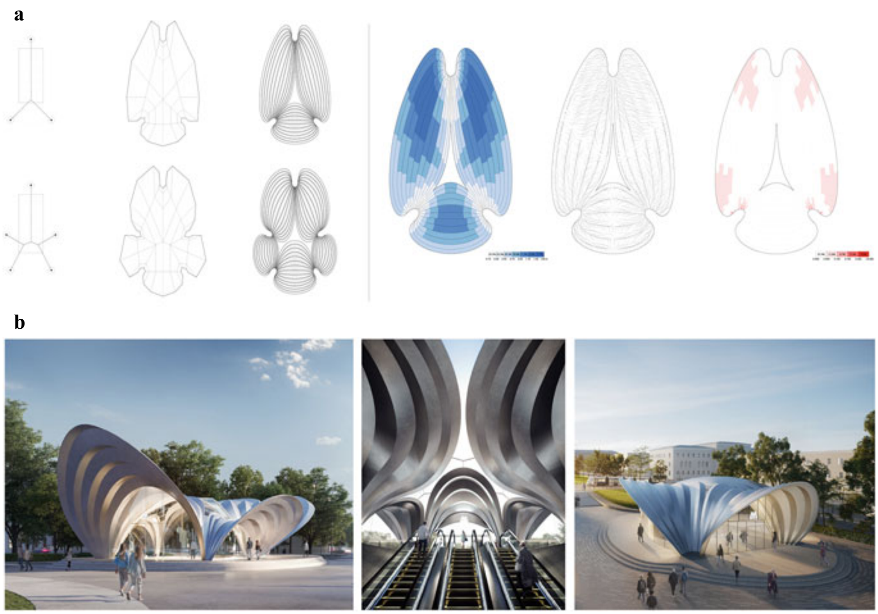

Fig. 13.5 **a** Dnipro Metro Station, Procedural generation of shape from input graph, geometry analysis and rationalisation. **b** Dnipro Metro Station, Exterior and Interior views of the entrance shell canopy

technology stack to create toolsets that are either non-existent or unavailable within commercial design environments. It requires both time and monetary investment in R&D to create and develop sandbox tools which can be field tested via the creation of digital and physical technology demonstrators.

PGC is also currently expensive to make physically as the twentieth century automation-centric production systems are misaligned with STS. Thus, it is currently reliant on RDF and other early-stage technologies and methodologies for its physical realisation.

13.4 User Generated Content and Professionally Generated Content

The motivation to democratise features of AG via web services and game platforms in lieu of PGC is driven by several factors. The desire to deliver mainstream architectural design via a broad base of authorship, effectively crowdsourcing Architecture Engineering and Construction (AEC) practice, has been a long goal. The homebuilders, developers, regulators, and municipalities have looked into it for the purposes of increasing housing stock rapidly, often to the detriment of unit type mix or amenities on offer (Wilson and Barton 2022). The end user is disillusioned in this process resulting in spaces offering utility such as high density yet unfit to serve on cultural criteria such as pedestrian friendly, vibrant, ecological, and economic sustainability (Jacobs 1992; Newman et al. 1996). Likewise, efforts to relinquish centralised regulatory control for instance in housing Permitted Development Rights (PDR), have proved useful optimisations decentralising regulation for specific scope. This included ways to expedite planning permissions, end to end development and engaging of home owners directly (Ministry of Housing 2019).

Democratising co-authorship and participation in design process by non-experts conventionally occurs through the lens of community round tables, focus groups, and town hall meetings to share, disseminate and collate data toward project planning. This often fails to capture the relevant stakeholders or users themselves and fails to be bi-directional dialogue as the design develops and gathers 'inertia.' Alternatives to this model shift thinking toward participatory models of housing and urban design inherited from board games. The participation model is turn based, incentivised, and provides a real time barometer for the 'status' and relative success of the proposal (to those who are playing).

Democratised design poses the distinct opportunity for agile decision making whereby users can change their minds, test and evaluation solutions, shift priorities, arriving at other solutions, and the result is reflective of a changing landscape of decisions (Malmgren et al. 2009; Nahmens and Mullens 2009), not predictable from the outset or deterministic in its resultant form. This offers the distinct advantage of user focussed, consensus driven, market tested solutions which will flourish and be relevant end to end (Hofman et al. 2006; Barlow 1998; Schoenwitz et al. 2012).

Aesthetic and Technical Considerations

The way in which we evaluate STS for UGC is through the 'technical' performance such as polygon budget, limits of computing resources on a device, and the 'social' performance such as user experience, interaction richness, and dramaturgical features of social setting, appearance, and manner of interaction, each contribute to the overall performance of the scheme (Goffman 1956).

There are specific technical and creative challenges to democratising user generated content. The authors of UGC are not likely to have a design background creating the necessity to distribute and encode design 'knowledge' unnecessary in PGC. Technical competencies in software engineering, systems theory, Information Technology (IT) and product development become important as UGC shifts toward STS (Szafir et al. 2016; Moritz et al. 2019; Tang et al. 2011; Langer 1997; Hallstedt, et al. 2020). For instance, UGC is the result of a selection process, not a CAD drawing and creation process in the conventional designerly sense. Not only do a set of selections need to be present, but they also need to be multifarious anticipating a diverse user audience. The creation and management of assets alone introduces workflow challenges of procedural model definition and real time geometry creation. In addition, support for diversity of technical functions including computing resource for physics calculation, rendering, data reconciliation, and synchronisation is needed (Ball 2021).

Further to this is the importance for evaluation and analysis utilities to sort, filter, and return relevant content in the myriad of potential selection objects and corresponding attributes (Nardini et al. 2019). Visual rather than syntactical wayfinding is needed for STS which employs creative capacities in the realm of User Experience (UX) design to develop intuitive and immersive graphical user interfaces (GUI). Through the creation of Augmented Reality (AR) overlays and Heads Up Displays (HUD) product data can be communicated seamlessly, intuitively, and customised to local user profiles and preference (Liu et al. 2010; Chapanis 1959).

Technical considerations include discretisation of system space for digital modularity, as well as preservation of curvilinear shape through discrete voxel representations of content containers.

Trends Toward Industry Alignment of STS

Geometry-based abstraction of complex structural and manufacturing phenomena is an integral feature of AG. This means that many of its core technologies are easily transported to non-expert CAD platforms such as web browsers and game platforms. Gaming platforms are increasingly considered for 'gamified' solutions that require social engagement, multi-stakeholder participation, and negotiation of trade-offs.

The move away from standardised dimensional elements toward mass customisation of assembled components (Sears Roebuck and Co 1936) is supported through innovations in fabrication technology and DfMA (Wood 2021; Thuesen and Hvam 2011). The variability of such coupled with the desire for real time gameplay suggests procedural content generation utilising lightweight inputs as is the case for PGC. Further to this, the creation of in game selections, simulated city fabric and even game level design requires parametric, real-time creation utilising adaptive components for user consumption and design assist creation. This fundamentally makes use of a technology stack for lightweight computation, deployment in series, and field-tested accumulation of knowledge to a common core framework. This suggests a natural extension of end-to-end pipelines to the end user in early design which is technically feasible, and can directly be harnessed for content creation, without an intermediary 'architect.'

Game titles such as Fortnite, Roblox, Second Life, are increasingly de-emphasising goal-oriented gameplay, encouraging the use of the cyber physical for social fulfilment and best practice gameplay mechanics through cooperative play and interactivity (Ross 2014; Maloney 2021; Fabricatore 2007). This coupled with the increasing demand for digital marketplaces for online bidding, negotiation, valuation, collaboration and mechanisms to enhance trust and credibility to potential buyers poses new creative territory where utility for volumetric space alone is not strictly viable (World Economic Forum 2021).

State of UGC

The metaverses are currently too far removed from reality—skirting the boundaries of fantastical, a universe empty by default, operating under its own mechanics. The visual cues are foreign, graphically coarse, or primitive and unintuitive to conventional user wisdom. At the time of publishing, AltspaceVR, Somnium Space, Decentraland each exhibit promising ideas to incentivised building, are navigable, and offer users the opportunity to perform certain utility functions, however they are still non-immersive, interaction sparse, unintuitive, and crude in assimilation to user (Decentraland 2020; Somnium Space 2019; AltspaceVR 2013). This can improve by becoming more familiar by adopting some of the mechanics, 3d-ness, and photo-realism of the physical world to make more intuitive and seamless the experience of switching between online and on-land. This would result in the cyber physical being a precursor-to or as an extension-of the physical experience—an augmented reality not a superseded reality—thereby improving the user experience. We are beginning to see this shift for instance in Non-Fungible Token (NFT) sales by both Christies and Sotheby's in metaspaces as well fashion house exclusive releases for the metaverse by both Gucci and Burberry (Criddle and Klasa 2023).

Benefits of STS in UGC

The following case studies illustrate the benefits of using STS in the design of UGC.

Role of Platform Technology

Platform design initiatives started in 2018 through academic settings at the Architectural Association Design Research Lab (AADRL) and subsequently through ongoing development at ZHA and through workshops, the ongoing studio at AADRL Nahmad-Bhooshan Studio and University College of London (UCL) Bartlett AD RC10. Shifting design thinking to game technologies and platform development at ZHA using Unreal Engine has empowered our capacity to disrupt conventional procurement processes and bring together stakeholders to deliver high value, locally relevant, resource effective, supply chain integrated design solutions.

Platform design helps to *test fit scenarios, explore contingencies, simulate eventualities* to explore the universe of feasible solutions. It facilitates the design of market tested, demand driven solutions delivered and rapidly assembled with more certainty resulting in less risk.

Beyabu Honduras: A Technology Platform and Residential Configurator

The Beyabu Honduras configurator is the latest build in a lineage of residential platforms developed in Unreal Engine offering investors, occupiers and developers ways to position properties onsite to suit, evaluate metrics, and monetise features such as air and development rights in the process. The participants configure modular building components in real time using a web-based application.

The configurator leverages ray tracing to achieve the highest levels of visual fidelity for both the interior and exterior of units. Pixel Streaming enables ZHA to share the configurator experience remotely from the comfort of the participant's browser and device of choice. At the time of publishing the configurator had been used across three different sites exhibiting dramatically different landform characteristics to configure communities.

The platform format brings stakeholders together into a digital marketplace to digitally simulate and negotiate viewpoints in a real time participation platform. This goes beyond the typical product configurator selecting colours, materials, or fixtures in the Ikea-like or real estate spec home catalogue. Users are invited to select from the beyabu residential portfolio of typologies, as well as sequentially position themselves in the community prompted only through certain incentives, including proximity to others, proximity to amenities, total view cone from hill height, as well as real time feedback on selection costs and implications to the aggregate community.

This has demonstrated that AEC industries can engage stakeholders in the design process to co-author, effectively crowd sourcing and democratising the design process. This in part is made possible through a decentralised governance approach in the Honduran Zones for Employment and Economic Development (ZEDE) (Fig. 13.6).

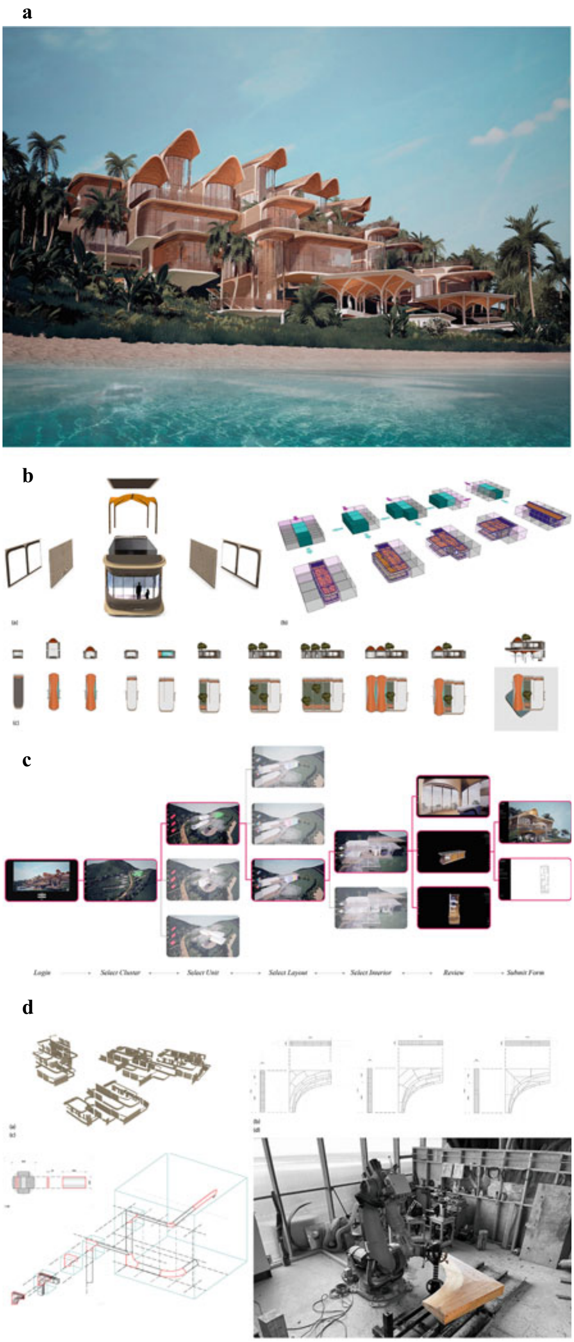

Fig. 13.6 **a** Beyabu configurator—Platform technology and gamification for real estate development. **b** Beyabu configurator—A digital kit of parts encoded to voxels resulting in unit variations. **c** Beyabu configurator—Online user configurator. **d** Beyabu configurator—Robotic assisted digital timber end to end supply chain integration. (**a**) timber cladding elements (**b**) bespoke glulam part creation (**c**) assemblage in relation for discrete spatial representation, (**d**) robot processing of timber element. Image Courtesy of Circular Factory at Hooke Park. **e** Beyabu configurator—Raw user data

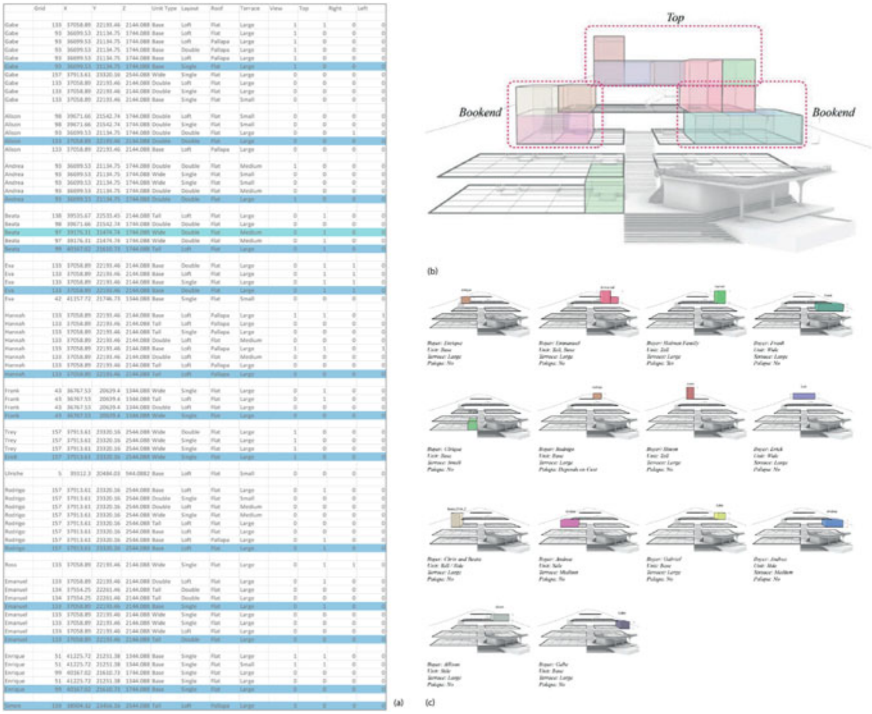

Fig. 13.6 (continued)

Liberland—A Cyber Physical Incubator for Decentralised Finance, Governance, and Urban Planning

The nation of Liberland will first launch through a virtual metaverse to its e-citizens and supporters around the world before its physical launch sometime thereafter. Liberland Metaverse is differentiated from contemporary metaverses for its focus on crypto and the blockchain technology ecosystem in lieu of the entertainment sector. Investment in Liberland Metaverse gains a stake in the physical Liberland. In addition, it is differentiated by its urban and architectural design of the interaction-rich and immersive 3D spatial environment. The urban fabric is characterised by broad open spaces, outdoor activated public spaces, radiating outward from a Central Business District comprised of a series of event venues such as NFT plaza, Decentralised Finance (DeFi) plaza, Exhibition Centre, Incubator, and City Hall. The urban governance model is applicable to both virtual and physical Liberland, leveraging a plurality of planning principles, to offer choice to potential developers, investors, buyers, and end users. These are explored in various districts of Liberland in each sponsored order, self-governed order, and spontaneous order outskirts through a variety of revenue and ownership structures.

Liberland is an attempt to merge the metaverse and web 3.0 vision with urban planning as a decentralised, open participatory model of spatial technologies and governance technologies. It demonstrates there is a mutual relationship between online architecture, urbanism and on-land and as such, can be exploited to enrich, augment, and further fulfil the citizenry experience and economic prosperity of the nation (Fig. 13.7).

Fig. 13.7 **a** Liberland—a cyber urban incubator. **b** Liberland—(**a**) Incubator Building, (**b**) module variations, (**c**) arrangement variations

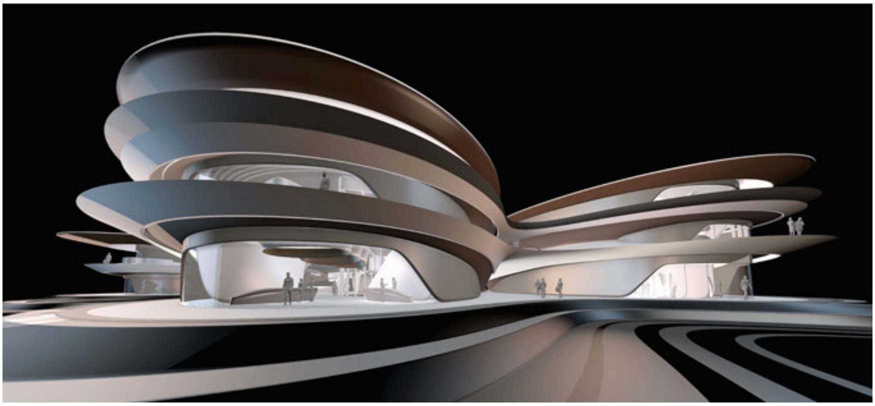

Fig. 13.8 **a** PUBG mobile—Erangel Hospital 2050

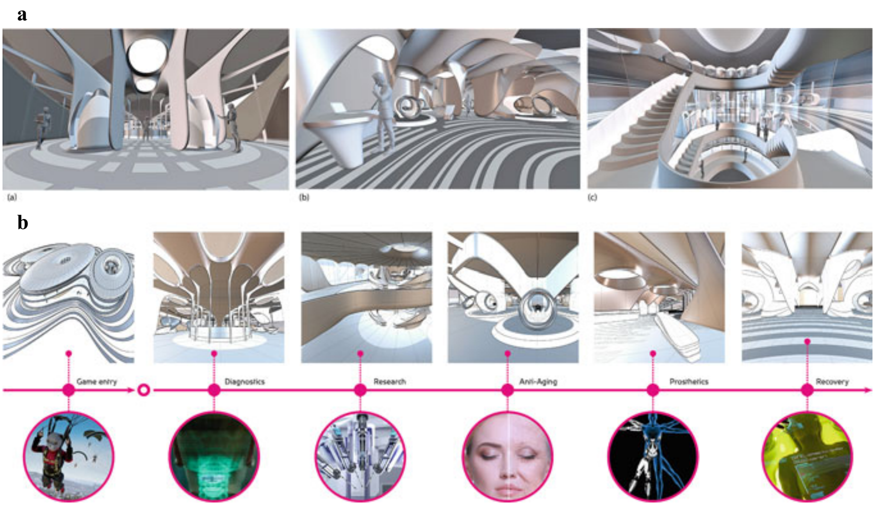

Fig. 13.9 **a** Novel multiplayer battle royale gameplay experiences. **b** Interior differentiation for varied user strategy and tactics and replay value

Player Unknown's Battlegrounds Mobile—Medical Centre

ZHA's joint effort with Player Unknown's Battlegrounds Mobile (PUBG-M) is testament to our deep belief in user-experience (UX) focused design, new technologies of spatial design, novel media of spatial experience, and inter-disciplinary collaboration. The partnership was valuable to reinforce our investment to advance our collaborative, designer-friendly, spatial UX-focussed parametric design technologies.

Spatial designs for the medical centre consider user experience, interaction and navigational aspects that are adapted to 3D shooter game play for each first-person shooter (FPS) and third-person shooter (TPS) scenarios. The online architecture is designed as three interlocking buildings with each one relating to a futuristic hospital use theme—robotic surgery, anti-ageing and longevity research, recuperation and preventative medicines. The furniture and scene entourage were designed in accordance with this creative theme as well as the utility they would serve for sight lines, shelters, and bunkering in gameplay tactics. One of the key design features is the central open atrium space, which whilst providing a clear understanding of how to navigate the building also opened novel vertical combat scenarios, both close and far combat options, and provided players building access via the open rooftop (Figs. 13.8 and 13.9).

13.5 Discussion and Outlook

The discipline of AG is consolidating the research and demonstration gains from its first decade of existence, and progressing towards full scale and mainstream architectural applications with ongoing efforts at the research epicentres in Stuttgart, Zurich and elsewhere (IntCDC 2019; NCCR_dFab 2017; Block et al. 2020). The maturation of several start-up businesses in RDF along with the encoding of expertise in reusable code assets for ease of creation and manipulation of AG, further reinforces this trend of rapid industrialisation of manufacturing and construction technologies (ODICO 2012; AIBuild. AIBuild 2015; BranchTechnology 2015; Jacobson et al. 2016; Mele et al. 2017).

The BIM paradigm, given its documented lack of development, has failed to deliver on its promises of integrated project delivery (IPD), virtual design and construction (VDC) frameworks for delivery of projects (Martyn 2020; Eckblad et al. 2007; Olofsson et al. 2007). This in combination with the difficulty to consider/ represent most discrete geometry representations—predominant information streams in RDF & AG—as building information models (Tolman 1999) making BIM misaligned with the progress in geometry processing, mass customisation. With the paradigm of design for manufacture (DFMA)—using manufacturing input at the earliest stages of the project to design parts that can be produced more easily and more economically (Poli 2001)—taking prominence, STS has the potential to take centre stage as it aligns and is easily embeddable to the software tool chains and collaborative platforms associated with DFMA (Richard 2021; ODICO 2022). Such collaborative platforms aim to incorporate most of the early promises of BIM including:

- increasing engagement of construction knowledge—traditional & RDF—in the design process (Eastman et al. 2011; Khemlani 2009; Sacks et al. 2010);
- developing detailed design earlier than has been common with traditional systems.
- seamless exchange of data and intent among collaborators to reduce time and facilitate iterative refinements (Bhooshan et al. 2018a);

- Increasing flexibility and non-collocated teams (Sacks et al. 2010).

Whilst the deep market moat of BIM helped it to survive the misalignment with RDF & AG, its misalignment with the current production stacks of metaverse and UGC could make it difficult to survive this time around.

The immediate outlook for Spatial Technology Stack (STS) is to significantly improve its prospects of mainstream impact—reducing the costs associated with its digital creation by in turn capturing and encoding the significant tacit know-how that is currently part of the creation process and thus its cost. Such a synergy already underway in the graphics community—Geometric Deep Learning—would help further open the solution space and its exploration, whilst addressing the cost of digitally creating PGC with potential machine assisted creation of Professionally Generated Content (PGC), and would provide a sound basis for disruptive, industry-wide applications of STS in Architecture, Engineering and Construction.

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