PrismArch

Deliverable No D1.1

Report on current limitations of AEC software tools, leading to user and functional requirements of PrismArch

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Abstract	Report on existing practices and describe indicative problems that VR- and non-VR-aided design environments are facing with respect to the architectural designers and engineering needs. A suggested list of user and functional requirements will be included in the report to drive developments. Finally, an initial version of the principles, rules, and constraints in the form of taxonomies will also be provided based on AKT's existing knowledge base.
Keywords	Requirements, architecture, engineering, principles, rules

Copyright

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List of abbreviations and Acronyms

Abbreviation	Meaning
AB	Advisory Board
AEC	Architecture, Engineering and Construction
AIA	American Institute of Architects
ARB	Architects Registration Board
BBP	Better Buildings Partnership
BEP	BIM Execution Plan
BIM	Building Information Modelling
BREEAM	Building Research Establishment Environmental Assessment Method
BRISA	Building Services Research and Information Association
CA	Consortium Agreement
CAD/CAM	Computer-Aided Design & Computer-Aided Manufacturing
CDE	Common Data Environment
DoA	Description of Action
DR	Deliverable Responsible
EIR	Employers Information Requirements
FEM	Finite Element Modelling
GA	Grant Agreement
GFRC	Glass Fibre Reinforced Concrete
HVAC	Heating Ventilation Air-Conditioning
IBC	International Building Code
ICC	International Code Council
IP	Intellectual Property
ITAV	Information Technology AudioVisual solutions
IPR	Intellectual Property Rights
NDA	Non-Disclosure Agreement
PC	Project Coordinator
QA	Quality Assurance
R&I	Research and Innovation
RIBA	The Royal Institute of British Architects
ToC	Table of Contents
WP	Work Package
UG	User Group
VR	Virtual Reality*

*Virtual Reality for the PrismArch project means a mixed reality simulated world. Our understanding of VR extends to all digital means of simulation and interfaces between machine logic and human perception, including all variations captured under the terms XR, AR, mixed reality, and augmented virtuality. Two-dimensional worlds are not an exception of this (i.e. access from desktop monitors, tablets, phones etc.)

Executive Summary

This rather extensive deliverable is a holistic approach into the needs of the basic AEC disciplines namely Architects, Mechanical, Electrical, Public Health, and Structural Engineers from VR environments. The general scope is to enhance collaboration in immersive spaces by providing tools that enable a smooth workflow before, during and after the construction of a building. The structure of the deliverable is as follows. In Chapter 1, an introduction into the modern era of building design is provided especially under the prism of recent investigations of a fire disaster in a tower in the United Kingdom. In Chapter 2, the principles of work and design for the basic AEC disciplines are provided in a manner that reveals the requirements from new VR systems. In Chapter 3, the use case partners, namely ZHA, SWECO and AKTII provide 4 buildings designs that will be used as PrismArch use cases. In some cases, the designs images are blurred in order to hide information which is held under a non-disclosure agreement between them and their clients. If potential interest exists please communicate with the authors (ZHA, SWECO, and AKTII) to request more details. In Chapter 4, the requirements analysis methodology and the collected requirements are presented.

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Zaha Hadid Architects (ZHA) - ZH VR Group

https://www.zhvrgroup.com

Working with clients that have global reputations for excellence, Zaha Hadid Architects (ZHA) has redefined architecture for the 21st century with a repertoire of projects that have captured imaginations across the globe. Form and space are woven within the structure of buildings that evolve from their surroundings and tie disparate programmes together. Enticingly contextual, each project combines an unwavering optimism for the future with concepts of connectivity and integration.

Receiving the highest honours from civic, professional and academic institutions worldwide, ZHA is one of the world's most consistently inventive architectural studios—and has been for four decades. These 40 years of research are inscribed within every design. ZHA's architecture is defined by its democratic attitude, offering generous public spaces inside and out. The ideology within each design is applied with a light touch as well as principled discipline; engaging the city with an act of attraction rather than imposition.

ZHA's optically rich interiors are built essays in spatial composition. They invite exploration so that space becomes personal, owned by all visitors as they interact with each other and the surrounding architecture. Mathematicians acknowledge the purity of ZHA's formal geometries and fluid lines, but this architecture also engages the senses and captures the eye; creating unrivalled spatial experiences that are clearly organized and intuitive to navigate.

Marrying innovative digital design methods with ecologically sound materials and sustainable construction practices, ZHA does not look at the disparate parts, but works to understand them as a whole; delivering practical solutions to the defining challenges of our era.

Each project by ZHA is the very specific assimilation of its unique context, local culture, programmatic requirements and intelligent engineering—enabling the architecture and surrounding urban fabric to seamlessly combine, in both formal strategy and spatial experience.

In over 50 award-winning projects around the world, ZHA's architecture becomes more refined spatially, more efficient structurally, more polished materially, more advanced technologically—and generally more resolved—with each new design. Their clients commission buildings, and ZHA meets the programmes, but ZHA also reads between the lines to exceed each brief and consistently deliver the shared aspirations of a new generation.

Collaborating with visionary clients, communities and industry experts on more than 60 on-going projects, ZHA's hugely talented and dedicated teams of over 400 experienced professionals work with passion and commitment to honour Zaha Hadid's legacy and create transformational projects on six continents.

ZHVR GROUP: Zaha Hadid Architects have been a constant driver of highly specialised design solutions and technological innovations. Among these revolutionary developments the office led the early adoption and transition to a fully digitised 3D design process. This enabled the studio's leadership in digital design coordination and manufacturing. Since 2014 **ZHVR GROUP** has been working with several developers for hardware and software to adopt the emerging VR technology into architecture and design. In order to realise the potential of VR and the medium's intrinsic value for bringing about an ontological shift, ZHVR Group develops VR experiences and presentations for building projects and also focuses on VR-specific designs. An additional interest and part of the mission statement is to develop Immersive Modelling Tools. ZHVR Group holds several partnerships with the XR Industry and the construction industry to develop a novel way for designers to collaborate and design inside augmented reality.

Starting in 2014, ZHVR Group's work, involving in-house production and collaborations with external specialists included; the introduction of VR Kits and VR Workstations for real-time VR, stereoscopic still images, and animations; enabling internal design evaluation and client presentations; and numerous in-house immersive visuals for client presentations and competition entries. These visualisations cover the scope of Architectural and Interior Design Work.

AKT II

https://www.akt-uk.com

AKT II is a progressive design-led practice of consulting civil and structural engineers, façade engineers and bioclimatic engineers, with a proven track record of providing a high quality, innovative and well-managed service. We bring a proactive approach to all of our commissions, always with the goal of establishing the client's needs and offering the most appropriate engineering solutions with respect to design, quality, cost and programme.

We engage with the client and wider team at each design stage to deliver ideas and solutions of the highest quality, which are underpinned by a keen knowledge of modern construction techniques and leading-edge analytical tools. We have a wide and varied range of projects overseas, all of which have been delivered from our London office through either partnership with local consultants or with full delivery services. Innovation in the design and construction industries is frequently driven by technological change and discovery. As a leading design-focused engineering firm, AKT II has always perceived these changes as opportunities to uncover novel design strategies, and to create efficiency and add value throughout the entire construction process. Since the earliest years of AKT II, this approach has been exemplified by p.art, our **Parametric Applied Research Team**. The singular remit of this cross disciplinary group – consisting of engineers, architects, computer scientists and parametric designers – is to explore and capitalise on new opportunities via technological and software development. To achieve this, p.art carry out in-depth research into new materials, construction and fabrication techniques, as well as creating new digital tool sets and software interfaces. The diverse interests and expertise within the group include structural optimisation through form-finding, environmental analysis, machine learning, live occupancy sensing, and many more. All of p.art's agendas are supported through academic engagement with leading architecture and engineering faculties at universities across the UK and worldwide, however the work is emphatically not a series of academic exercises; p.art often works alongside other design teams within AKT II to apply these advances to real-world design projects, which also ensures that knowledge gains are disseminated and embedded across the entire company. One of the critical efficiencies that p.art brings to projects is **Re.AKT**, a **unique software ecosystem developed inhouse over the past six years. Re.AKT II directly interfaces with a host of different industry-leading modelling, BIM, structural analysis and drawing production software packages, to form an interlinked and holistic design environment**. This enables design teams to rapidly collaborate and refine their work, and ensures that all aspects of the project are coordinated through a single 'master model'.

This advanced toolkit is available to all engineers and CAD technicians within the company, allowing them to perform structural form-finding, produce engineering documentation and automatically generate 2D or 3D fabrication information from that unique synchronised source. An advanced Bioclimatic Design Toolkit [BioToolkit] has also been developed by p.art, capable of simulating in high fidelity the complex environmental conditions, such as thermal and wind comfort (see Figure 0.1), which emerge within existing and proposed urban spaces. This toolkit has significant speed and accuracy advantages over previous techniques, and can be used to rapidly simulate, assess and optimise across many stages of the design process. It has already contributed to a number of successful planning applications and winning competition entries, and is now being expanded to encompass other aspects of environmental performance, such as structural wind loading analysis and internal smoke egress simulation. Other emerging strands of research include the assessment and integration of virtual and augmented reality interfaces, and development of on-site information sharing platforms. As with many of the interfaces p.art develops, these new tools operate at a multitude of scales, from small pavilions to connected buildings, all the way through to the realm of smart cities.

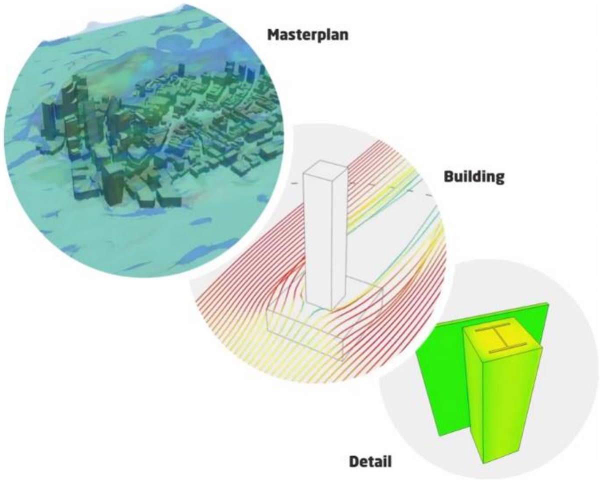

Figure 0.1: Bioclimatic design for Wind Engineering, Comfort & Resilience, and Building Physics.

SWECO

https://www.sweco.co.uk/

SWECO aims into producing sustainable buildings, efficient infrastructure and access to electricity and clean water. With 17,500 employees across the United Kingdom and Europe, we offer our clients the right expertise for every situation. We carry out projects in 70 countries annually throughout the world. Our commitment is to be the most approachable and committed partner with recognised expertise. We are governed by curiosity, commitment and responsibility at all levels.

We believe it should be easy doing business with Sweco. Our model is a decentralised one. Every consultant is responsible to deliver, and empowering each consultant is Sweco's strength. While we are one of the largest consultants in urban development, the decentralised approach allows us to be close to our customers, understand their needs and ultimately deliver.

As building professionals, we critically assess and communicate the risks, opportunities and solutions at each stage of the project, through a range of workshops, site visits and milestone approvals. Our multidisciplinary offering allows us to work holistically with all stakeholders, ensuring our designs are technically robust whilst also delivering elegance and value.

We provide analysis, design and site monitoring for all aspects of building-related projects. Our expertise and knowledge allow us to design and deliver solutions which minimise the use of natural resources and provide value for our clients throughout the project life cycle.

Innovation: Our success in technical innovation involves working closely with both industry and research institutions. For us, research is a crucial element of every project and is applied in equal measure to cost, buildability, maintenance and technical performance. We have established global links with both academic and industrial research facilities and, when appropriate, we make use of our experience in mock-ups, performance evaluation, life-cycle testing and computer simulation.

Sustainable leaders: Buildings have a significant impact on the natural environment, and governments are, understandably, introducing regulations to promote the principle of sustainability. Our highly qualified engineers have, for many years, led the way in promoting the best in practical and sustainable design. Every project has its own unique signature and is evaluated on its own merits to ensure optimal solutions are adopted.

We evaluate the feasibility of passive design measures, to reduce environmental impact, prior to investigating active systems. Our experienced engineers ensure that systems proposed in the design of the projects follow the principle of 'keep it simple' such that sustainability targets are met. Sweco has joined the Better Buildings Partnership (BBP)'s Design for Performance (DfP) scheme [DfP] as a Pioneer Delivery partner, as part of our ongoing commitment to improving sustainability in the built environment. Increasingly, buildings must be environmentally friendly and able to demonstrate this through benchmarking against a range of sustainable targets, some of which are imposed by law and regulations.

We are registered assessors for the Building Research Establishment's Environmental Assessment Method (BREEAM) and the Home Quality Mark (HQM). These have established themselves as the de facto standard for measuring building sustainability. We offer assessments against a wide variety of BREEAM standards. Many of our buildings have achieved the highest BREEAM and other environmental assessment ratings. We offer practical and independent advice on building performance and labelling during all stages of the project.

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1. INTRODUCTION AND RESEARCH OBJECTIVES

The main objective of PrismArch is to achieve a synergy between multiple authoring and reviewing parties for the AEC industry by locating the collaboration within a singular immersive and experiential collaboration space, and to look at the design development holistically throughout the entire life cycle of the architectural project, from pre-concept to archiving. The desired outcome is a unique platform to connect all architectural project stakeholders who are presently siloed in their respective disciplines (including clients, architects, structural engineers, MEP engineers, project managers, contactors, etc.) and to synthesize the disconnected digital information.

To achieve this aim, we must examine what disciplinary demarcations will be necessary within the unified data sphere, and envision innovative data structures and data handling methodologies. All project information must be contained in one singular and flexible information structure that is capable of sustaining the entire project ecosystem (we can imagine this system working similarly to the SDKs of the i-Phone, NVidia's Omniverse [Omniverse], and [Nucleus Server].

PrismArch's scope therefore involves the following aspects: information semiology, experiential aspects (photo-realistic and abstract representation), information registration, management, and visualisation (for architectural 3D assets), and the application of artificial intelligence.

Information processing requires a unique information framework suited for gathering and storing, and a cognition system that is both 1) a dedicated system, and 2) unique to the geometry and the setup of the information. As an analogy, we can look at the human nervous system and the brain (Figure 1.1), where the central location of information allows the convergence and ability to process this data. The physical separation of information spaces is no longer a technical requirement in the AEC industry, but a carryover of history and tradition. The images of semiconductors merging with biological nerve cells (Figure 1.2) suggests that a unified design space is already technologically within reach. Not only from a conceptual level, but also on a physical level, we are close to merging biological reality with technological reality. The data can be potentially visualized in tree shaped nodes such as in Figure 1.3, where each node level presents a different level of detail for each AEC discipline, commonly known as LOD in architecture (see Table 2.1 in Chapter 2).

Figure 1.1. The biological/anatomical information and data processing system

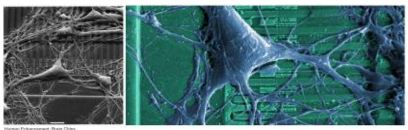


Figure 1.2. The fusion of biological nerve cells and human-made data processing technology

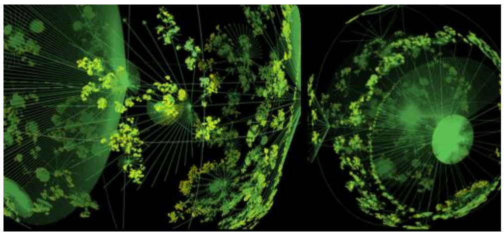
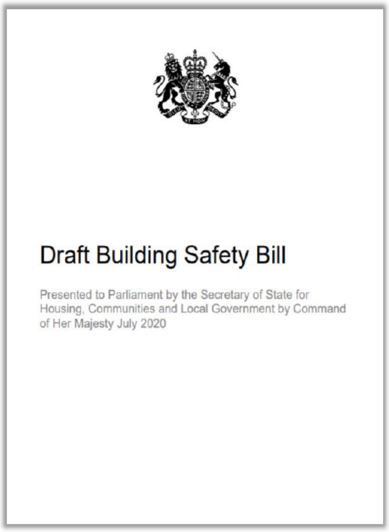


Figure 1.3. Visualized complex data trees with information nodes, "3D hyperbolic graphs of Internet topology created using the Walrus visualisation tool developed by Young Hyun at the Cooperative Association for Internet Data Analysis (CAIDA)", https://www.caida.org/tools/visualization/walrus/

The data created with the current (siloed) information system already has a high level of complexity. When converging it in PrismArch, we will need to maintain the professional demarcations of the authors, and ensure sure that all contained information is identifiable. The extent to which PrismArch aims to record information related to and associated with projects exceeds what we have previously achieved within the AEC industry. Similar to the way that internet topology can be represented as data trees with information nodes using 3D hyperbolic graphs [figure 3], bringing all the layered information into a single space will allow the totality of project information to be viewed as a singular event / singular entity. PrismArch will create new ways of storing and processing information, because the traditional methods of capturing and storing information keep the AEC practitioners artificially in our separate authoring spaces. The aim of this research is to prove that all the project information is able to be contained in the singular space.

The main purpose of D1.1 is to identify the requirements and parameters of this singular design space needed to streamline the communication and data transfer inefficiencies of the traditional AEC workflow. However, the aim is to move beyond streamlining the current workflow, and to create the possibility for novel efficiencies to emerge that could revolutionise the way we collaborate. The intent of this research objective is to review and illustrate the current methodology and practices of each of the cross-disciplinary design partners of the consortium, ZHVR, AKT-II, and SWECO, to arrive at a blueprint of requirements and specifications in order to guide the project research and technical objectives, highlighting the current limitation in BIM, reviewing the available technology, and providing examples of existing immersive and/or collaborative AEC industry tools.

Despite the evolution of digital tools for the AEC industry, the narrative thread of a project's development is most often missing in current projects because no single record exists of the decisions that impacted the project's development. The storage and management of evolutionary project-related information is crucial for the evolution of the AEC industry, and will soon be required by new regulations in the UK. The UK presently is going through a regulatory overhaul of the entire AEC industry based on findings of Dame Judith Hackett, who is leading the investigation into the industry's regulatory body following the Grenfell tragedy [Grenfell 2017, Hackit 2018]. This is the largest review of UK health and safety since 1945.


Draft Building Safety Bill

Presented to Parliament by the Secretary of State for Housing, Communities and Local Government by Command of Her Majesty July 2020

Figure 1.4: Version 2020 of the Building Safety Bill. Image copyright Barry Hembling of Watson Farley & Williams, 2020

In the draft Safety Bill [Draft Safety Bill 2020], currently under review in Parliament, UK Legislation is introducing the Golden Thread Principle, requiring a detailed and traceable safety record of all the decisions made throughout the lifetime of the project: from early decisions during design through legacy handovers and maintenance and repairs of the completed building. This new system of mandatory occurrence reporting, a golden thread of information running through all parts of the building, will become a manual that will cover a building during the entire lifecycle. The golden thread will begin with information about early design decisions, tracing why the building was designed in a certain way, continue through the design development and construction phases, and then to building use and maintenance, noting any repairs. This will not only provide a wealth of information for informed decisions, but also make it possible to follow the golden thread record in case of a building failure, to allow the regulator to determine who was at fault.

Figure 1.5: Interim report of 2017 about the Grenfell fire accident. Image copyright Barry Hembling of Watson Farley & Williams, 2020

A detailed contemporaneous method will be required to keep track of what changes were introduced and why (such as value engineering). If the building safety design is compromised in any way, the architects will be held accountable. Sign-off of building on completion is likely to involve co-signing compliance with approved inspector, architect, and contractor. The idea is that the architect needs to understand what has been designed, so that the architect can so-sign along the inspector.

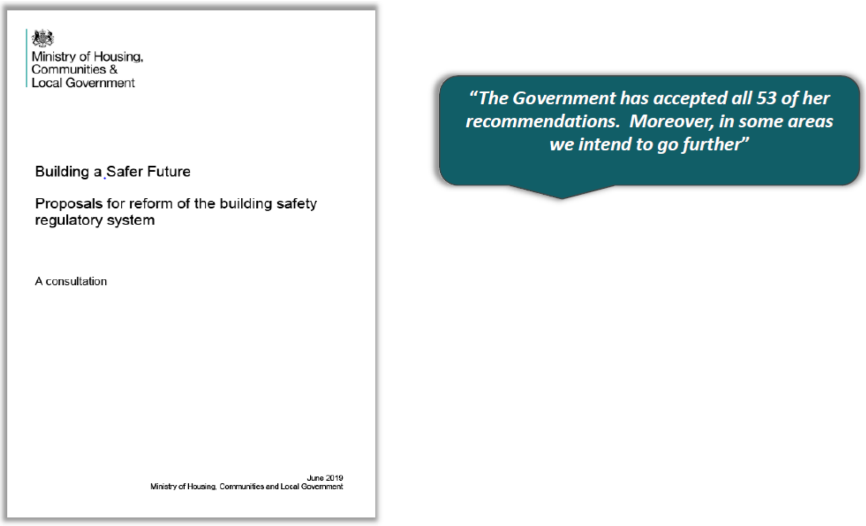


Figure 1.6: Version 2019 of the proposals for better safety in buildings. Image copyright Barry Hembling of Watson Farley & Williams, 2020.

The above is highlighting a need for a unified review and record-keeping platform that can be used to consolidate and keep track of the review and decision-making process during the entire lifecycle of a project. We see no better way of doing this than in VR, whereby bringing the embodied experiential aspect to the simulated project, facilitating the most informed and realistic encounter with the developing design. We envision PrismArch as a review space, communication, visualisation, and project management tool that handles high resolution immersive space as well as documentation and recordkeeping, allowing all parties involved in the creation and maintenance of a building to converge in a single experiential space.

Methodology followed in this deliverable

Our activity involves analyzing the workflow of an architectural project, i.e., the order of architectural and engineering design sequence; defining how simulations are used in the AEC industry; and identifying the current limitations of the existing BIM (Building Information Modeling), CAD (Computer-Aided Design), CAE (Computer-Aided Engineer, Simulations) software, as well as the available VR software for the AEC industry. Current software allows for easy and accurate modeling of complex three-dimensional designs, so rather than placing the focus exclusively on content creation, we look closely at the communication and knowledge exchange between various design partners in the contemporary design process. Our aim is to highlight the vast amount of secondary information required currently to communicate and transfer information successfully among partner disciplines and out to the client. Our findings are based on our internal project folder data, e-mail communication, and direct input from the team members. We are not able to review the phone conversations that took place, and thus cannot evaluate how these influenced the efficacy of the information exchange and absorption of the new information.

Outline of this deliverable

In Chapter 2, we introduce the responsibilities, obligations, and the authority of each of the three design disciplines - architecture, structural engineering, and MEP. Because all three design partners are UK-based, this report reviews the AEC Industry through the lens of the UK's governing bodies. However, it is important to mention that every country has its own regulatory body, and although there are many similarities between the international boards, there are many key differences also. For example, the path towards licensure differs from country to country, varying in the duration and level of education and type of apprenticeship required, all across the world [see Comparative Analysis of Architectural Education Standards Across the World] and in Europe, as outlined by the Architects' Council of Europe (ACE) [see AEC: how to become an architect]. The relationship between each discipline and its design tools and methodology is also explored in Chapter 2, and examples of current AEC tools used by each partner is provided.

In Chapter 3, we look at case studies from each discipline, finding a common denominator and rule-sets through reviewing project-related events. We begin by mapping the project development process from the vantage of each of the design partners, focusing on the areas of communication and knowledge and data transfer that are inherent in the current design workflow. To capture the widest possible range of design and collaboration experience, each design partner focuses on mapping two selected projects from their portfolio. Each project is analysed from the standpoint of "incidents," or notable key events in the life cycle of the project that had defined its development. We document what software was used in each incident, and map this information to arrive at a holistic, wide-angle view of the project development ecosystem within the AEC industry as evidenced by our real-world project data.

In Chapter 4, based on the findings in Chapters 2 and 3, we proposed several user and functional requirements that are needed for VR environments. The analysis of the requirements is performed using a "Requirements Shell" which is a unit that describes a requirement from many perspectives most stemming from [IEEE 830, Marcelino 2014] such as "Unambiquity" and "Completeness".

2. ARCHITECTURAL, ENGINEERING AND CONSTRUCTION INDUSTRY

2.1 Responsibilities, liabilities and authorship assemblies

An architectural project requires input from multiple disciplines including clients, project managers, architects, engineers, consultants, contractors and the project development is a collaborative effort coming out from the assemblies. Despite the collaboration aspects, because each disciple has its dedicated responsibility, obligation and authorship, the project development is traditionally represented as a linear process. Existing market attempts to innovate technology to facilitate the project authoring process, e.g. [BIM 360] which is the closest product to the goal of bringing multiple disciplines together into a singular design space. However, the innovative potential still remains unrealised as the current software solution has little recognition for the multidisciplinary environment and per se continues to be an l authoring tool for the siloed disciplines. The lack of openness of the tool and the high entry threshold of required information and project definition makes it dysfunctional for the architectural discipline to adopt at the early stage of the design.

Every architectural project is an assembly of the segmented multi-disciplinary work cycles. The work cycles of discipline are segregated due to the nature of the traditional/historical work methods, and this is reflected in the current selection of tools. Discipline-specific authoring tools cater to the distinct workflows within the AEC industries.

Stage reports, authored by project disciplines and submitted to the clients to keep a history, record and track of decisions made at each project development stage, can be seen as a bookmark of synchronised thoughts across the project disciplines. The submitted document does not necessarily reflect all the real-time decision-making processes in an individual discipline scope.

Each discipline's start point is different, for instance, architects are appointed from the early concept stage of the project to develop the project brief with the clients and engineers come in later stages of the project to refine the design options developed and received from the architects.

The architectural discipline and engineering disciplines do not see design as a linear process, whereas the MEP discipline enters at a later stage and tends to view design as a progressive definition of the MEP elements. For instance, the MEP engineers are not as likely to have to offer multiple design options directly to a client.

Engineers might have in-house developed libraries of pre-set principles or options that can be adapted to the proposed architectural design options, yet architects might want to mine and create new design inspirations and options considering a cultural point of view as well as to tailor the design to the clients. Architects highlight problems by executing concept design development and engineers suggest potential solutions (options) with their expertise. It can be said that having multiple disciplines at an early stage enables the project disciplines to avoid risks of changing plans or construction methodology, and this will also benefit the clients to manage financial aspects more carefully. Multiple disciplines being involved in an architectural project from an early stage can also offer opportunities to brainstorm the brief from multiple perspectives and this would influence the entire project proposal as well as its management system.

The Royal Institute of British Architects [RIBA 2020], Appendix 7.2 suggests that input from a consultant at an early stage of the design can help clarify the design brief and avoid financial and management risks:

- Determining the need for specialist consultants is a key task at **Stage 1**. For example, the appointment of an acoustician might be essential for a school next to a railway line.

- At **Stage 2**, specialist consultants should develop their Project Strategies, focusing on, as a minimum, any aspects impacting on the Architectural Concept or the Cost Plan [RIBA 2020].

RIBA only being one of the examples of architectural work plan, however, these rules can be applied globally as architectural projects can be international and vary depending on the building regulations.

Particularly useful in all stages is the Building Information Modelling (BIM). The primary role of BIM in the workflow is about sharing information and working together. BIM enables everyone to access all project data at any time, as everyone is connected to the BIM common data environment, also known as BIM platforms. Effective use of BIM can result in a gain in productivity between 20% and 60% (see Figure 2.1) [MacLeamy Curve 2004]. The use of new digital tools is tied to the reduction of errors as well. Below is the chart which shows the comparison of BIM workflow vs the traditional drafting workflow.

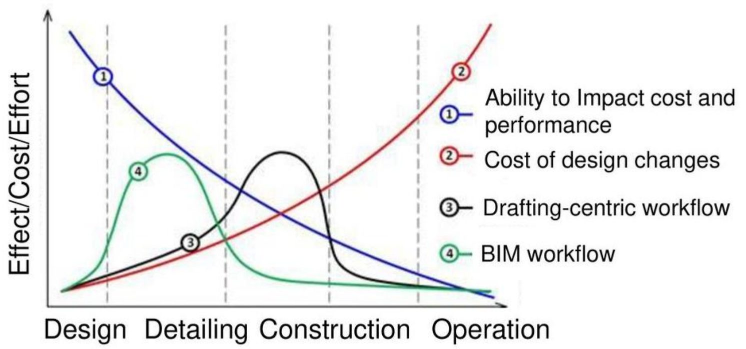


Figure 2.1: Improvement in efficiency by using BIM workflow instead of traditional drafting methods, "The MacLeamy Curve".

The idea and aim of Building Information Modelling (BIM) is to use a shared digital representation of a built asset to "facilitate design, construction and operation processes to form a reliable basis for decisions" [BS EN ISO 19650-1:2018]. The basic notions are stated below.

BIM Employee's Information Requirement (EIR): The Clients/Owners have a significant role to play in the BIM process. They are the one who should be driving and encouraging BIM. There is no complexity or size a project should reach to be BIM-enabled. Typical EIR shall have the following information.

- Purpose Scope
- BIM objective and uses
- Project details
- Management requirements
- Technical requirements
- Commercial requirements

Once a project team is assembled, and stakeholders' roles and responsibilities are defined, the client collaboratively participates in creating a BIM execution plan with key project stakeholders.

BIM Execution Plan (BEP): BIM Execution Plan (also known as BEP) helps to outline the goals of the BIM process. BEP enables the project teams to understand critical deadlines, produce required tasks/work, and explain why that work is crucial for project success. BEP will have all the essential information about the project (this will provide an overview of the project scope to anyone who is not familiar with the project). Typical BEP shall have the following structure:

1. Project Information: This Section shall have the necessary information about the project such as Project Owner, Project name, Project Location, Project Description, Project duration, Contract type, Cost, etc.

2. BIM Project team Directory: All the project members' contact details such as company name, Name of the individual, email, phone number, and responsibility shall be listed here in the form of a table. This list will enable the members of the team to contact each other should there be any questions related to the project

3. Design Stage Milestones: This Section shall have information about Project design stages with the start date and completion dates.

4. BIM Roles and Responsibility: This Section shall have the necessary information about BIM roles and responsibilities like Client's BIM representative, Consultant's BIM Manager, Architecture BIM Manager and BIM Coordinator etc.

5. Design BIM Goals and Authorized Uses: This Section shall have information about BIM objectives and uses such as Visualization, Design authoring, 3D coordination, Digital fabrication etc. It also provides information about Authorized uses.

6. Model Types and details: Information about the production model shall be populated here. These models can be Design Intent Model, Contractor’s Model, As-built model or Record model. This Section will also provide information about Model sharing platform, model exchange frequency, milestone, file types, software programs used, software versions, shared coordinates, naming conventions, standard file sharing format etc.

7. Digital Collaboration: Digital collaboration process during the BIM-based project delivery will be provided here. This Section shall have information about BIM360 (or similar) collaboration site, project admins, contact information, collaboration locations, scheduled updates etc.

8. Linking Strategy: Information about the linking strategy will be provided here. The Section explains whether it is One Model Strategy, Multiple Model Strategy, Floor based linking, Nested linking, Cloud linking etc.

9. Model Control Strategies: This Section shall have information about model control strategies. This includes worksets, naming conventions for new worksets, copy/monitor, Coordination views, phasing, Design options etc.

10. LOD (Level Of Detail) Matrix: This section provides information about how much detail and information should be in our BIM. Table 2.1 includes the definition for various LOD commonly used. Table 2.2 is an example of a filled LOD matrix.

Level of Development (LOD)	Definitions
100	Conceptual
200	Approximate geometry
300/350	Precise geometry
400	Fabrication and assembly
500	As-built

Table 2.1: Level of Detail

Revit Family Categories	Model Development Category per LOD					
	50/51	100	200	300	400	500
Air Terminals				DB/FB		
Cable Tray Fittings			DB	FB		
Casework			DB	FB		
Ceilings			DB	FB		
Columns			DB/FB			
Communication Devices			DB	FB		
Conduit Fittings			DB/FB			
Data Devices			DB	FB		
Doors				DB/FB		
Duct Accessories				DB/FB		
Duct Fittings			DB/FB			
Electrical Equipment			DB	FB		
Electrical Fixtures			DB	FB		
Entourage	DB					
Fire Alarm Devices				DB/FB		
Floors			FB	DB		
Furniture			DB	FB		
Furniture Systems			DB	FB		
Generic Models		DB/FB				

Table 2.2: Example of a filled LOD matrix.

11. Pre-Construction Model Checklist: QA process during the BIM-based project delivery can be found here. Below, in Table 2.3, is an example of the sample checklist.

<u>MEP Checklist:</u>

#	Checklist Text	Conformance		
		Yes	No	N/A
1	Ductwork shown at the right size and location			
2	Piping shown at the right size and location – including slopes			

<u>Structural Checklist:</u>

#	Checklist Text	Conformance		
		Yes	No	N/A
1	Beams at correct depth			
2	Cross bracing modeled			

Table 2.3: Example of a checklist of BIM

12. Clash Detection: This Section shall have information about who maintains the Federated model, frequency of clash detection meetings, frequency of model exchange, the process involved in clearing the clashes etc.

BIM requires to set up the Information Requirements for a project, and to enable this to work, the project requires a **developed 3D model**. This also affects how architects would develop 3D models. The decision making on the implementation of BIM technology needs to be done by the clients and the project disciplines before the project starts. In any case of BIM implemented projects, each discipline's scope and responsibilities on creating the data and the purpose of the BIM application must be clearly mentioned and agreed in the contract. BIM requires specific knowledge and the project might require a BIM consultant. The project disciplines might need to change their existing traditional workflow to adapt to the system if the team does not have experience with it.

In fact, [RIBA 2020, p.100] mentions that "setting the Information Requirements for a project is a huge task for architectural projects now because the way buildings are briefed, designed, manufactured, constructed and used have been changing by technological influence". The author also mentions that the data is organic and the value may change across stages. The client and the project disciplines need to be aware of the risk: "Although the information might seem complete, it is likely to require further design iterations, to conclude the engineering aspects (including Engineering Analysis in Stage 3), coordinate it with Project Strategies and align it with the Cost Plan. It is simply not possible for information issued mid-stage to be fully coordinated; any client using such information needs to be aware of this.” The risk aso may come from accuracy of the data such as data collected and used for site survey.

Yet setting up the Information Requirements is required at a very early stage of the project development in order to run a project’s data coherently together with risks in any changes made throughout the stages, the BIM requires resolutions in the 3D asset. Meaning, even if the mutli-disciplinary collaboration happen from the beginning of the project life cycle, lower resolution design tools or incidents such as architects' hand sketches, 3d conceptual sketches, markups made during meetings at designers’ desk will never be involved in the Information Requirements package - unless there is an additional and customised top layer embedded into the BIM software.

RIBA states that architectural design development might remain as multimedia and all stakeholders should be on board at any stage: “Some architects may still work traditionally and wish to use sketches to convey the Architectural Concept. Others may wish to use virtual reality to walk the client around the proposals, and to issue a video of what the client has agreed to – as the core deliverable. The amount of supporting information required from other design team members will depend on the size and scale of the project. However, the Stage Report can be used to corral everyone’s efforts, and to record the decision making that has influenced this information. A core task during Stage 2 is to undertake Design Reviews. It is important that these involve all Project Stakeholders, so that their views are incorporated into the Stage Report. The Project Strategies set out in chapter Six provide more detail on how Design Reviews can be used to engage Project Stakeholders on key issues [RIBA, 2000, p. 100]”. This situation is depicted graphically in Figure 2.2 and Figure 2.3. The procedural emergent nature of an Architectural Project is depicted in Figure 2.4 that spans over 9 stages (subfigures). These stages express the time dimension in an architectural project that has to be taken into consideration in the PrismArch project. The next section explores responsibilities, obligations and authorships of each discipline in detail.

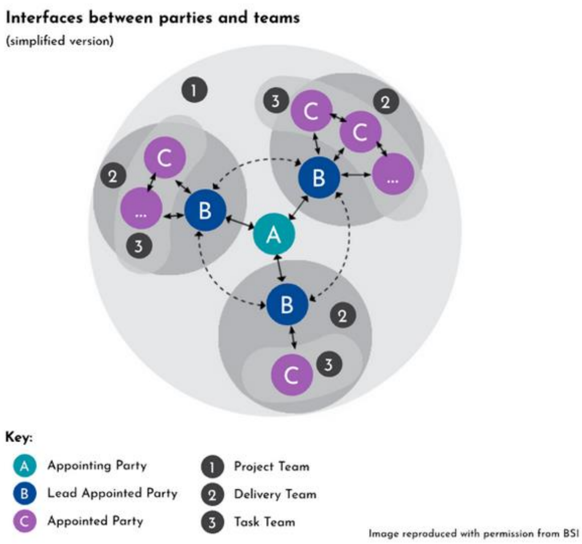


Figure 2.2: UK BIM framework, The overarching approach to implementing BIM in the UK, https://www.ukbimframework.org/ , https://www.cdbb.cam.ac.uk/

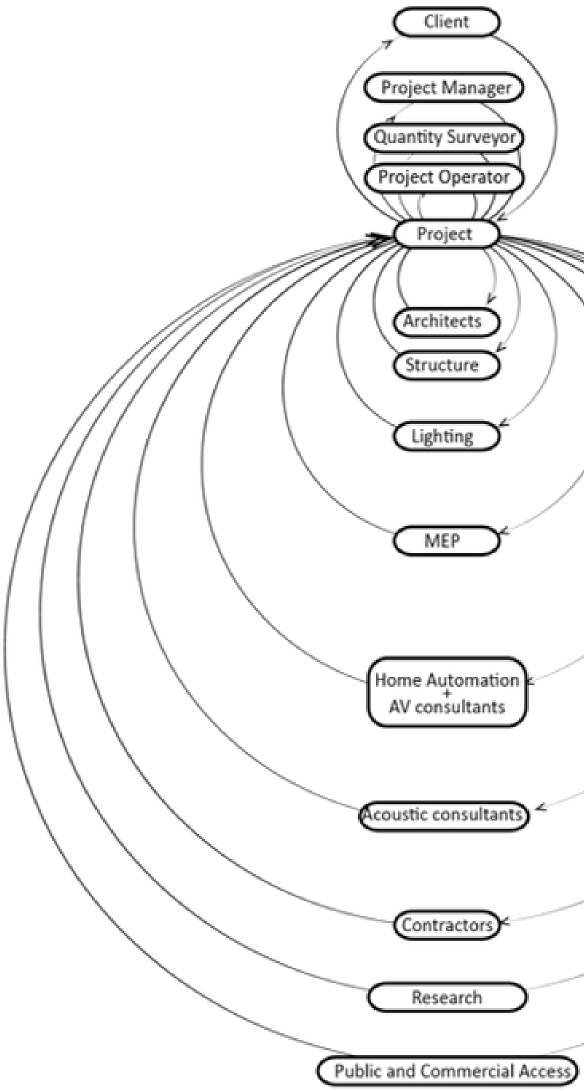


Figure 2.3: Project Assemblies Organized Workflow for a Project Disciplines Pilot Interior Project.

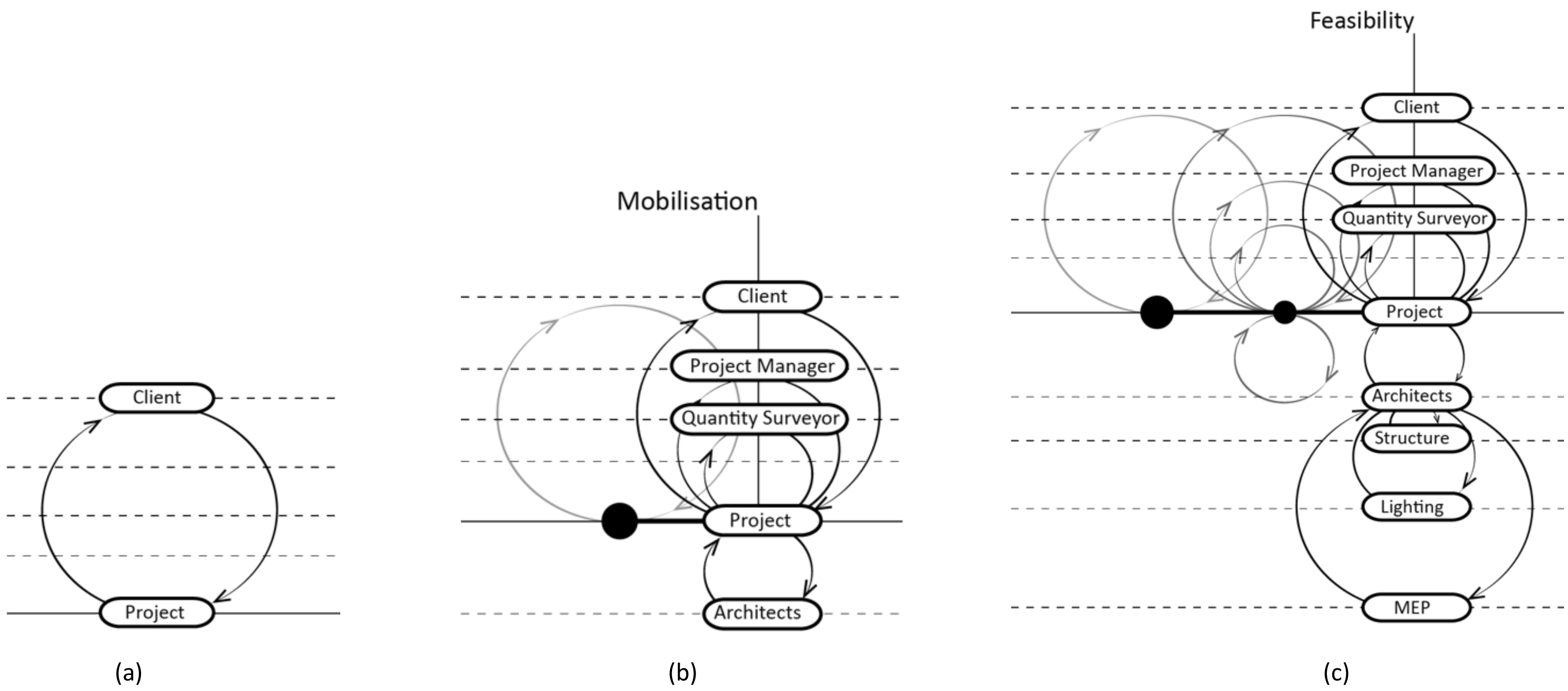


Figure 2.4: The initial workflow interactions: (a) Project requirements posed by the client; (b) The best means for achieving the clients requirements is confirmed; (c) Project Brief approved by the client and confirmed that it can be accommodated on the site.

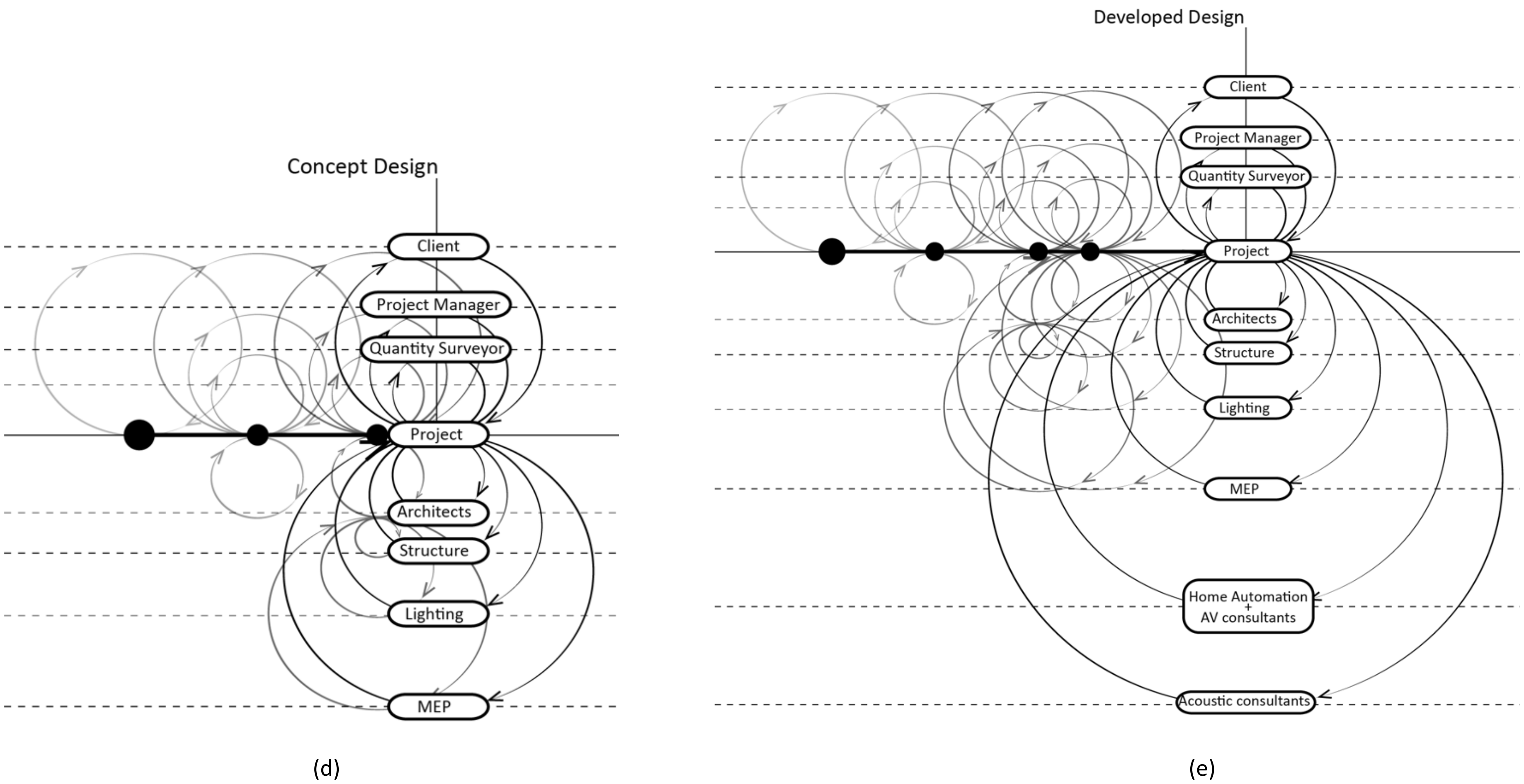


Figure 2.4: (d) Architectural Concept approved by the client and aligned to the project brief; (e) Architecture and engineering information spatially coordinated.

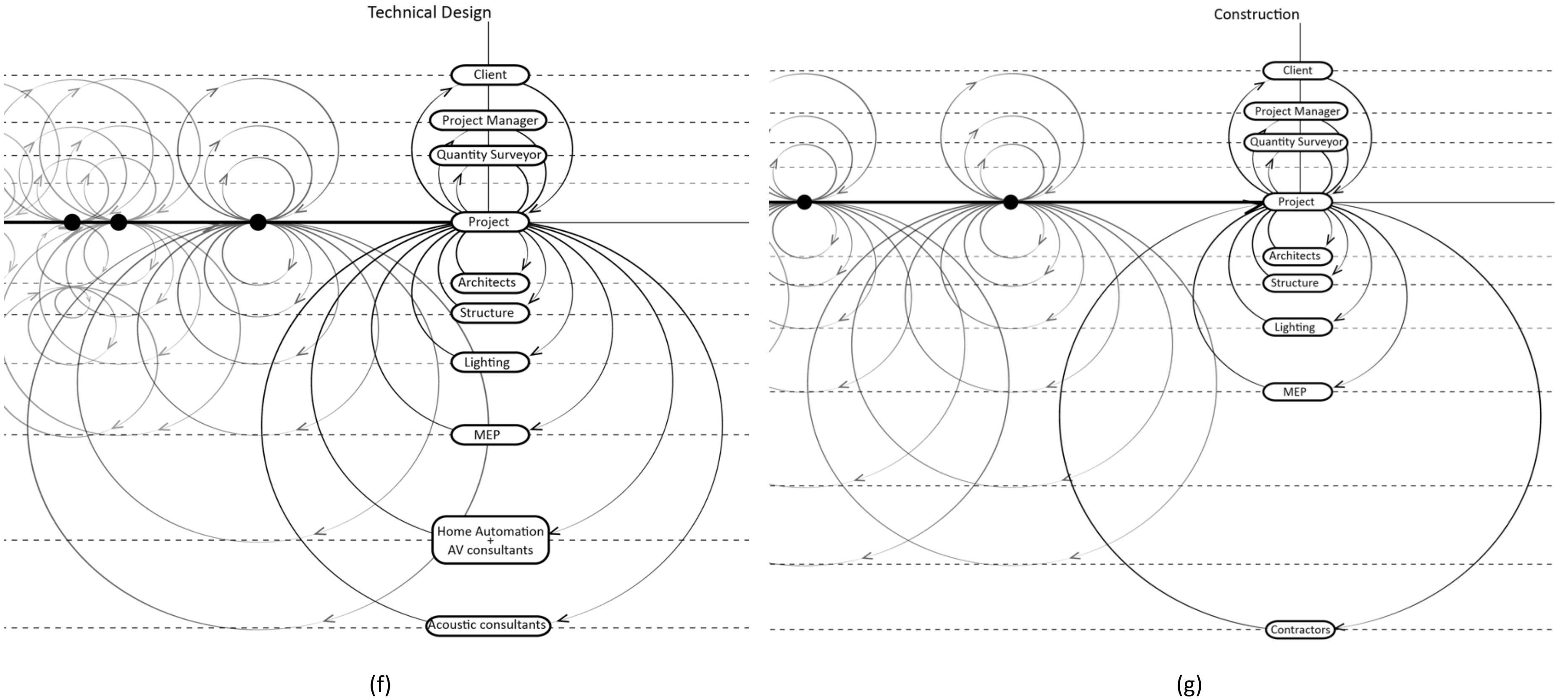


Figure 2.4: (f) All design information required to manufacture and construct the project completed; (g) Manufacturing, construction and commissioning completed.

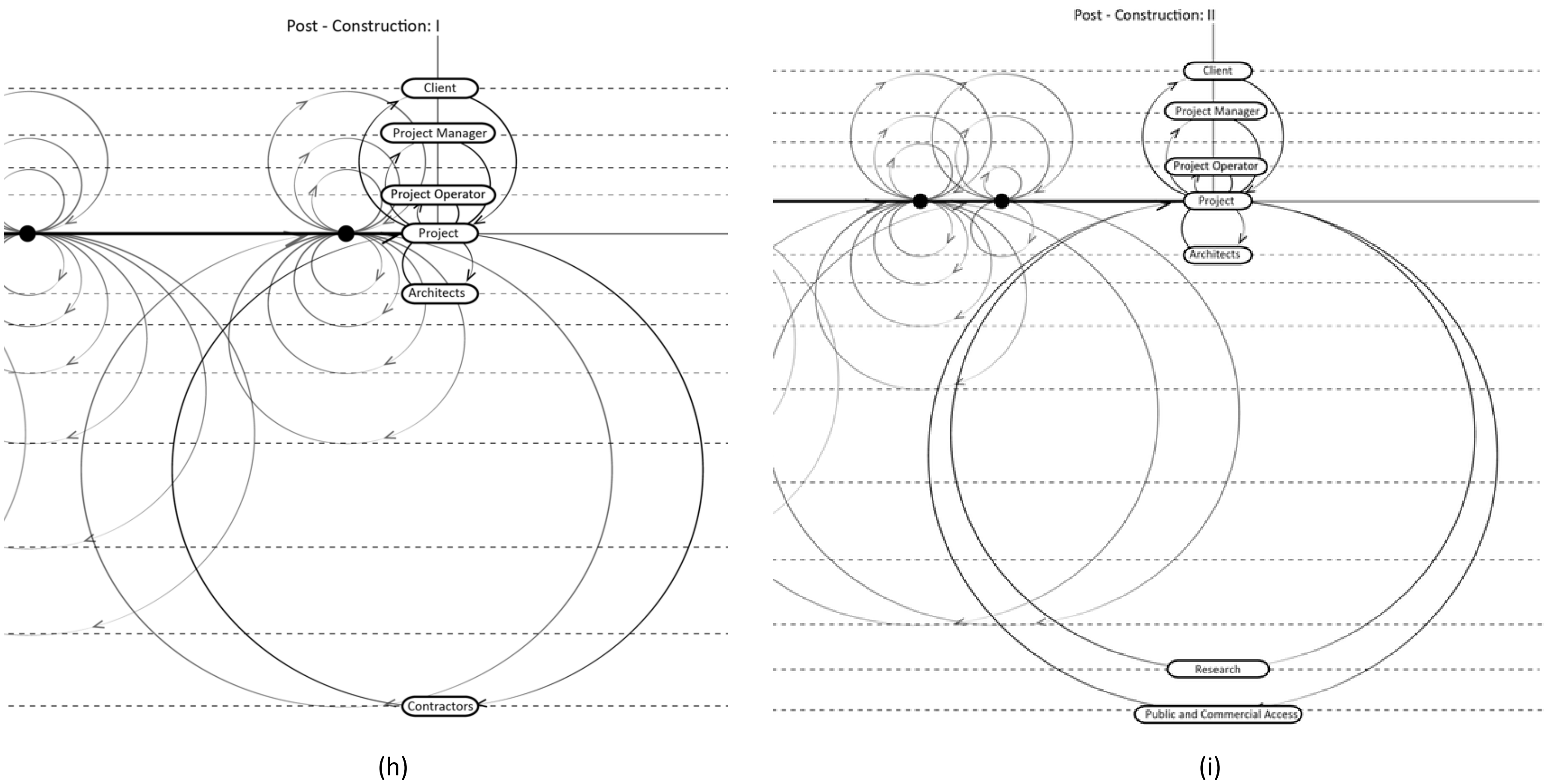


Figure 2.4: (h) Building handover; aftercare initiated and building contract concluded; (i) Project data for completed projects developed can be archived. In the future, the archived project data could potentially be licensed to public institutions (museums, galleries, etc) as well as for research purposes and it can be utilized for commercial purposes.

2.1a Architecture

Architectural Service

Architects are involved with projects from a start point and their responsibilities cover the entire project life cycle. This might include preparing a project brief with clients and determining a design plan considering cultural, environment, contractual and law, building regulation and financial aspects. The design process mostly involves 3D software programmes such as CAD drawing tools and Building Information Modelling (BIM) depending on each practice's design disciplines. The architect will consult with clients, contractors, engineers and other key members included in the contract to make sure the project input from each discipline is incorporated in a right order and matter. Their design requires modifications throughout the project life cycle as the project progresses and to be aligned with the project evolution.

According to [Designing Buildings Wiki 2020], Architect's responsibilities might include below:

- Helping the client prepare a strategic brief.
- Carrying out feasibility studies and options appraisals.
- Advising on the need to appoint other professionals to the consultant team, or independent client advisers, specialist designers, specialist contractors and so on.
- Advising on the procurement route.
- Contributing to the preparation of a project brief.
- Preparing the concept design.
- Preparing the detailed design.
- Preparing planning applications.
- Preparing applications for building regulations approval and other statutory approvals.
- Preparing production information.
- Preparing tender documentation.
- Contributing to the assessment of tenders.
- Reviewing designs prepared by others.
- Acting as contract administrator.
- Inspecting the works.
- Advising on the rectification of defects.
- Providing post occupancy 'soft landings' services.

Outside the immediate context of professional tasks and appointments, the architect must also act to promote his/her role in the commercial and cultural context. The outcomes of project work are used for building the architectural portfolio and establishing the company brand, and used in academic architectural and cultural discourse. In addition to meeting legal/professional record-keeping requirements, records are maintained for internal and aforementioned external purposes. Project data is archived and in constant use regardless of the project's completion status and timing. An architectural practice's design language is built upon the development of a portfolio and a legacy that has to the history of its own production, and access to the raw data as a reference.

The skills required to run a job might include below:

- Creativity: ability to visualise their ideas using multimedia tools including hand sketches, digital sketch, 3D modelling
- Research: architects are required to research materials and relevant cultural and economic subjects in order to formulate and present their concept. Reference images, concept, and material boards are often produced.
- Visualisation: ability to construct perspectives and produce conceptual drawings or photo-realistic drawings using multimedia tools
- Verbal Communication: ability to describe ideas to clients and colleagues
- Presentation: presenting ideas to clients
- Active Listening: understanding what others are sharing
- Problem Solving: identifying problems and proposing ways to manage them
- Critical Thinking: evaluating the possible outcomes before choosing the most beneficial solution

Below is an office structure and list of positions in a typical UK architectural practice. To be qualified as an architect, the candidates require 3 parts of education organised by the Royal Institute of British Architects (RIBA), and registration with the Architects Registration Board (ARB).

The term "Architect" is protected by the Architect's Act. Section 20 of the Architects Act states that *'A person shall not practise or carry on business under any name style or title containing the word "Architect" unless he is a person registered under this Act'* [ARB, Architects Registration Boards, 2017].

Positions in a typical UK architectural practice [Designing Buildings Wiki, 2020]:

- Architectural Assistant (training architects)
- Architectural Technician (specialising in the application of technology in architecture)
- Architectural Technologist (leading the technological design of the buildings)
- Newly Qualified Architect
- Project Architect (running a job with occasional guidance from a director)
- Associate Directors (responsibilities for overseeing several project architects)
- Directors and Senior Directors (oversee associate directors. Spending time with new clients and overseeing the management of the practice)
- Principal (Head of the office)
- Partner (Owner of the practice)

Before the work is undertaken, a written agreement, named as Contractual Setup and Agreement, must be signed between architects and clients as well as with other appointed members of the project.

- The contracting parties.
- The scope of the work.
- The legal system in which the contract is being signed.
- The fee or method of calculating it.
- Who will be responsible for what; also pertaining to the role of the architect inside the design team and during execution.
- Any constraints or limitations on the responsibilities of the parties.

- The provisions for suspension or termination of the agreement, including any legal rights of cancellation.
- Confirmation of adequate and appropriate insurance cover.
- The existence of any Alternative Dispute Resolution schemes that the contract is subject to and how they might be accessed.
- Details of the architect's complaints-/ and conflict-handling procedure.
- Confirmation that the architect is registered with the Architects Registration Board and that they are subject to the code.

The '*Architects Code: Standards of Professional Conduct and Practice*' states the architect's obligations which are summarised below (Architects Registration Boards 2017):

Architect's Obligation:
The architect has a duty of care:

- To exercise reasonable skill, care and diligence in accordance with the normal standards of the architects profession in performing the services and discharging the architects obligations.
- Provide adequate professional, financial and technical resources.
- A duty of care as defined in the relevant legal system.

A duty to inform:

- The client about progress and any issues that may affect the brief, construction cost, programme or quality.
- The client of the need to appoint others to perform work in connection with the project.

Collaboration:

- To collaborate with others named in project data or who's appointment is foreseeable and to integrate information into their work.

According to [ARB 2017], the authority of architects is below.

Architect's Authority:

- To act on behalf of clients in matters set out in agreement.
- To seek client approval to amend the design, terminate others employment or enter the client into contract with others.
- Standard forms of appointment

In the United Kingdom there are a range of standard forms of appointment available:

- RIBA Standard Agreement 2010 (S- 10- A) – Architect.
- RIBA Concise Agreement (C- 10- A) – Architect.
- RIBA Domestic Project Agreement (D- 10- A) – Architect (when using intermediate or minor building contracts on domestic projects).
- RIBA Sub- Consultant Agreement (SC- 10) – where one consultant appoints another to perform part of their services.
- RIBA Letter contract (domestic or commercial version) – for small works.
- ACA SFA 2012: ACA Standard Form of Agreement for the Appointment of an Architect.

- The CIC Consultant's Contract.

If a bespoke agreement is used:

- This is a matter of professional principle, commercial judgment and negotiation.
- Legal advice should be sought and the architect's insurers consulted.
- It is important to check there is only a 'duty of care' provision and not 'fitness for purpose'.
- It is important to check clauses relating to warranties, payment provisions, copyright, termination and disputes.
- The Housing Grants, Construction and Regeneration Act 1996 (Construction Act) will still apply as long as the client is not a consumer client.
- It should cover the same terms as the RIBA appointment to satisfy the RIBA code of conduct.

The architect's involvement in a project initiates communication with the client to form a project brief and settles a contractual agreement setup. As the project moves forwards, the architect develops the design while guiding the selection, optimisation and economisation processes, while controlling the realisation of the solution with other appointed project members. Within the scope, multimedia tools are applied to rationalise design concepts and consider the balance between aesthetics and functionality. Soft skills such as communication and presentation abilities are vital to manage the project coherently. Abilities to use software tools are also a strong advantage to run an architect's job more efficiently and accurately. Technology has influenced the traditional architect's workflow greatly.

Design Reviews

Internal design reviews include the project director, project architect, and architectural assistants with occasional guidance from principals. Design reviews can happen in a meeting room with a TV screen, at designers' desk or with a A1/A0 printed document or physical models. Hand sketches and verbal communications are the core driver of the discussion, and meeting minutes can be recorded during the reviews.

Management

External project managers can be appointed by the client depending on the project's contractual setup. These external managers are not part of the architectural practice, but they are an external consultancy service. Internally, the project is managed by the project director, by studying the needs of a project based on complexity and forecasting the amount of people needed for each design stage, as well as the necessary skill-sets required - thereby assembling a core team to work on the project.

Diagrammatic Drawings

Diagrammatic Drawings are often used in the concept design stage, to represent architectural plans and sections without detailed information. These drawings are presented to clients in an early stage of design development and these are also helpful to communicate with engineers to discuss structural systems and coordination. Some diagrammatic drawings developed for the project may be later used to communicate key architectural ideas and concepts to the public.

Presentation

Digital or hard copy documents are presented to the client as part of the contractual obligation. Presentation documents include project briefs and these are a compilation of selected design processes. These might include cultural research, area study, programs and circulation diagrams, massing study, diagrammatic drawings, structure and construction system, environmental analysis and photo-realistic images. Material boards are often produced by interior designers. The documents are usually presented by the Project Director travelling to clients' location or can be presented remotely using video conference tools.

Drawing Submissions

This is a general service that is part of the finalised production for a deliverable, and is submitted to the client. These submissions are done periodically and regularly, coinciding with partial deliverables, Quality Assurance (QA) checks, and as part of the final deliverable agreement. **Specialised Submissions, such as Planning Application submission and approval,** involve assisting the client to submit documentation to the statutory local authority. They are part of the architect's contractual obligation to submit information to a third party on behalf of, or in service to, the client**.**

3D sketch / Spatial Organization

3D modelling tools are used to sketch study spatial organisation and building forms. In the ZHA office, 3D computer graphic software is often used to sketch building forms and the result is brought to computer aided design (CAD) application software for rationalisation of the design. Volume calculations and simulations are also practiced along with the design and rationalisation process. Selected 3D models become a source of 2D line drawings including plans, sections, elevations, perspectives, as well as the source of photo-realistic and clay mode renderings.

Visualisation

Visualisation can be conceptual drawings, photo-realistic images or virtual reality experiences. Visualisation helps all disciplines to understand the overall look of the project - this includes programs, scales, materiality, structural espouse, facade design etc.

Current use of VR

Virtual Reality technology allows all disciplines to evaluate the project immersively for both internal and external reviews. Depending on the project budget, scale and presentation locations, 360 still images with standalone headsets or real-time image sequence with headsets plus tracking system are used to review contents. For external reviews and client presentations, Project Directors travel with hardware or prepare a setup and invite them to experience the content. For internal use, Project Directors and Project Architects review the content to make decisions on versions and also to understand the scale of the proposed design.

Current Communication Means used in Architecture

In Figure 2.5, the communication means that are employed when developing an architectural design are listed. The horizontal axis represents the phase where each mean is used and the ordinate axis represents the immersiveness level of each mean starting from simple hand sketches and ending on photorealistic and immersive representations such as Unreal and Twinmotion.

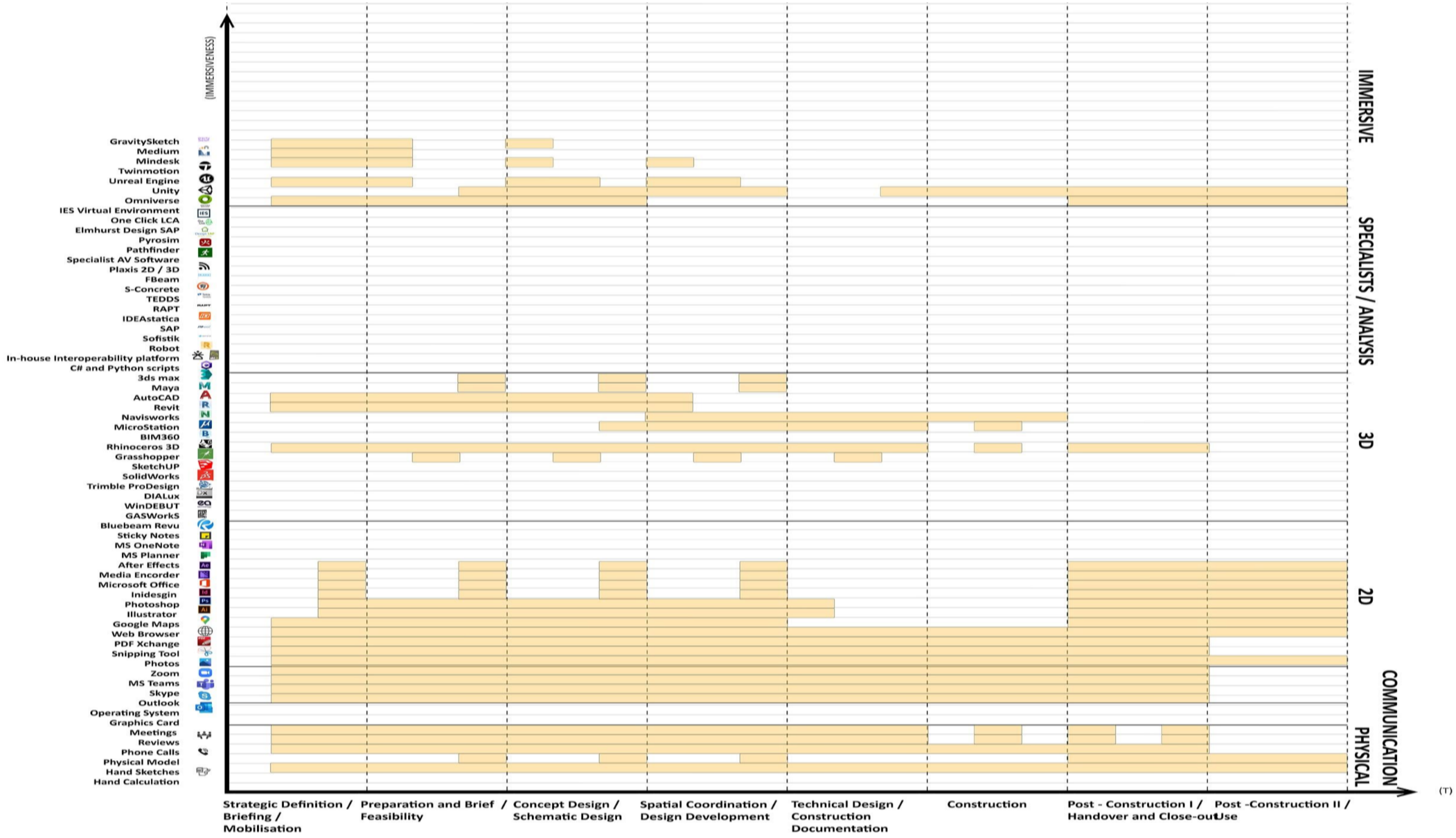


Figure 2.5: Current communication means for architectural design with respect to communication phase.

2.1b Structural Engineering

The role of the structural engineer is a key component in the construction process. Part of the wider discipline of civil engineering, structural engineering is concerned with the design and physical integrity of buildings and other large structures, like tunnels and bridges. Structural engineers have a wide range of responsibilities - not least a duty to ensure the safety and durability of the project on which they are working. Unlike architects, who must focus on the appearance, shape, size and use of the building, structural engineers must solve technical problems - and help the architect achieve his or her vision for the project. Structural engineers work in offices and on construction sites - or may split their time between both contexts. Locations can be varied, including work in metropolitan and rural environments. Depending on the size of the project, structural engineers may also be required to work long hours - in teams consisting of professional, skilled and semi-skilled workers.

Structural engineers must have a strong grasp of physics, three-dimensional conceptual skills and creative problem solving. Outside of an ability to apply principles of mechanics, mathematics and physics to construct safe, sustainable buildings, the roles and responsibilities of structural engineers include [New Civil Engineer Careers]:

1. **Design:** Many structural engineers deal primarily in the design of structures - calculating the loads and stresses the construction will have to safely withstand. Structural engineers should be able to factor in the different qualities and strengths delivered by a range of building materials, and understand how to incorporate support beams, columns and foundations.
2. **Investigation:** Before work can begin, structural engineers are involved in the investigation and survey of build sites to determine the suitability of the earth for the requirements of the upcoming project.
3. **Communication:** Structural engineers will be required to co-ordinate and consult with other members of their projects, including engineers, environmental scientists, architects and landscape architects. They may also be required to assist government bodies in their own inspections relating to the project.
4. **Management:** Structural engineers are often responsible for the organisation and delivery of materials and equipment for the needs of the construction project. The supervision and management of on-site labour may also be a necessity.

AKT II Service and Responsibilities: At AKT II in our typical involvement during a project, we undertake a review of the client's requirements as soon as we are appointed, to ensure that we obtain a full understanding of the project. Once the client brief has been established, the concept design stage commences together with a detailed desk study assessment of the site. In parallel with this we examine different forms of structure and types of construction with the architect, cost consultant and other members of the client and design teams. To ensure the correct solution is adopted, option studies are undertaken which take into consideration value, design, programme quality, adaptability, buildability and health and safety issues. As a practice we believe the most successful way of developing designs during the early stages is through design workshops. On completion of the concept design stage the scheme design stage is then progressed; the goal during this stage is to develop the design and determine the best holistic approach and the main structural zones, providing information to establish a detailed cost plan. Prior to the end of this stage we aim to arrange a value engineering session involving the client, potential contractors and all members of the design team to ensure that the appropriate form of construction has been adopted; at this stage a comprehensive risk assessment is also carried out. A detailed design report is then prepared, describing the form of structure for all the main elements, and the criteria to which the detailed design will be carried out. At the end of the scheme design stage, we continue to work with other team members to prepare detailed design programmes, which serve to identify all the main activities and interfaces with other parts of the team. These programmes are supported by information and required schedules, mutually agreed by all members of the team which list the dates for supply of critical information. The commencement of detailed design sees the mobilisation of our full structural team to complete the design calculations, structural General Arrangement drawings and a subsequent review. The detailed coordination of the project information is completed through design discussions, development of drawings and the checking of designs produced by other disciplines. For each project a Director is nominated as the senior member of, responsible for design throughout the agreed programme. In addition to the review undertaken by the project team, a Director not involved in the scheme on a day-to-day basis will also undertake an independent audit at critical points throughout the design process.

The positions in a typical UK structural consultancy practice are**:**

Board of Directors

Structural and Civil: Design Director, Technical director, Management Director, Associate Director/Associates, Senior Engineers, Design Engineers, CAD/BIM Managers, CAD/BIM Technicians

Administration: Office manager, Accounts/finance Lead, Marketing Lead

Legal: Commercial assistance,

IT: IT Lead, IT Technicians

IMS: Quality Management

Contractual Setup and Agreement

Description/Discussion

Design Reviews: Internal design reviews include project technical and design director, senior engineer and design engineers with occasional guidelines from principals. Design reviews can happen in a meeting room with a TV screen with an A1/A0 printed document, projected BIM models and or physical models. Meeting minutes are to be recorded during the reviews and hand sketches and verbal communications are the core driver of the discussion.

Diagrammatic Drawings: Diagrammatic Drawings are used throughout the life of a project, especially in the initial stages - to represent engineering plans and sections details and conceptual options without detailed information. These drawings are presented to clients in an early stage of design development and these are also helpful to communicate with the rest of the design team to discuss advancement in the design. A selection of those is often attached as appendices in the design reports.

Presentation: Digital (PowerPoint or keynote) or hard copy documents are presented in front of clients and design team representatives. Presentation documents include project briefs and these are a compilation of selected design processes appropriate for the stage the project is in. These might include **location research, area of study, programs and structural typology diagrams, material selection, diagrammatic drawings, structure and construction system, environmental analysis and photo-realistic images. 3d Printed models are sometimes brought along. The documents are usually**

presented by the Project Director or project associate travelling to clients' location or can be presented remotely using video conference tools.

Drawing Submissions

3D sketch / Structural simulation: 3D modelling tools are used to assess the architectural model updates shared by the architectural team. 2D - 3D computer graphic software is often used to sketch structural options, and the results are brought to BIM application software for rationalisation of the design. The analytical version of the BIM model is also exported into the structural specific simulation packages to assess feasibility of the options. Selected 3D models become a source of 2D line drawings including plans, sections, elevations, perspectives, as well as the source of photo-realistic and clay mode renderings for the purpose of presentations / reports.

BIM Approach

AKT utilises in-house BIM Managers, who are employed from the outset of projects to liaise with the client and other design team members to produce a joint project-specific BIM strategy document that is in line with the Employers Information Requirements (EIR).

This strategy document is typically a BIM Execution Plan ([BEP]), that sets out the scope of the model, the protocols for 'working together and interoperability', the BIM standards to be adopted, a 'Status Summary' outlining the principal uses of the model, and how the model will be utilised by the main contractor and how the final model will be used by the client. AKT has been producing and implementing BEPs for several years now, and they ensure a consistent and mature application of BIM across all projects.

For each project, the BEP describes in detail the following:

- BIM objectives and goals.
- Intended uses.
- Project-specific Standards:
  - Exchange file formats
  - Selected Object Libraries.
- Setting Out:
  - Datum points
  - Coordinate systems
  - Geographical systems/ projections.
- Naming and Classification Conventions:
  - AKTII naming for elements, files, drawing numbers in line with [BS 1192].
  - Structural elements assigned to a unified classification system [Uniclass 2015]
- AKTII Common Data Environment (CDE) Protocol:
  - Enables us to use the CDE to share models/documents and to assign the correct status. This ensures each design discipline can control how their information is used and distributed.
- Model production and delivery table.
- BIM Level of Development specification and Responsibility Matrix:
  - Determines Level of Detail (LOD) applied across each of the RIBA Plan of Work 2020 Stages.
  - Applicable to Building Siteworks, Substructure, Superstructure, Services, Special Construction & Demolition.
  - For most projects we typically comply with LOD 200 during Stage 2 (Concept Design), rising to LOD 300 in Stage 3 (Spatial Design), and LOD 300/400 in Stage 4 (Technical Design).

- AKTII Audit Form:
    - Ensuring that the digital data produced is compliant with AKT's internal standards.

AKTII is software platform neutral, however **our preferred BIM authoring platform is a combination of Revit and BIM 360** (both by Autodesk). To complement this, we have incorporated additional software and extensions such as Navisworks, Dynamo, Solibri, Rhinoceros and Grasshopper, to ensure that the finishal output - be it a native 2D/3D file, IFC model,CObie drop or structural model within a federated master model - meets the clients immediate needs and future requirements, such as facility and asset management.

To ensure successful delivery of the BEP, we have a continual programme of training (linked to our company IMS) for engineers and technicians at all levels. This training cover three main areas:

- Software
- Design
- Construction Knowledge
- Emerging technologies & Materials

Simulation: Structural, environmental and bioclimatic performance are assessed by using specialist simulation software packages that are specific to local requirements, material or detail of design. Typically to resolve structure, an overall FEM model is prepared to look into general issues of stability, loading and behaviour. Detail elements are designed instead in separate packages appropriate to the material choice.

Visualisation: Visualisation can be conceptual drawings, photo-realistic images/videos or virtual reality experiences. Visualisation helps all disciplines to understand the overall look of the project - this includes programs, scales, materiality, structural performance, facade design etc. It often involves post production software that allows to remove imperfections/ highlight specific elements. It is often used as part of the design process, and has a profound impact in the marketing as well.

VR: Virtual Reality technology allows all disciplines to evaluate the project immersively for both internal and external reviews. Depending on the project budget, scale and presentation locations, 360 still images with standalone headsets or real-time image sequence with headsets plus tracking system are used to review contents. For external reviews and client presentations, Project Directors travel with the hardware or prepare a setup and invite them to experience the content. For internal use, Project Directors and Project associates review the content to make decisions on versions and also to understand the scale of the proposed design. Occasionally we have also used VR in a live project, to allow the main designer to provide feedback on several different options of a design, including VR markup.

Current Communication Means used in Structural Engineering

In Figure 2.6, the communication means that are employed when developing an Structural Engineering design are listed. The horizontal axis represents the phase where each mean is used and the ordinate axis represents the immersiveness level of each mean starting from simple hand made calculations, continuing with advanced simulation software such as Grasshopper or Sofistik, and ending on photorealistic and immersive representations such as Unreal Engine.

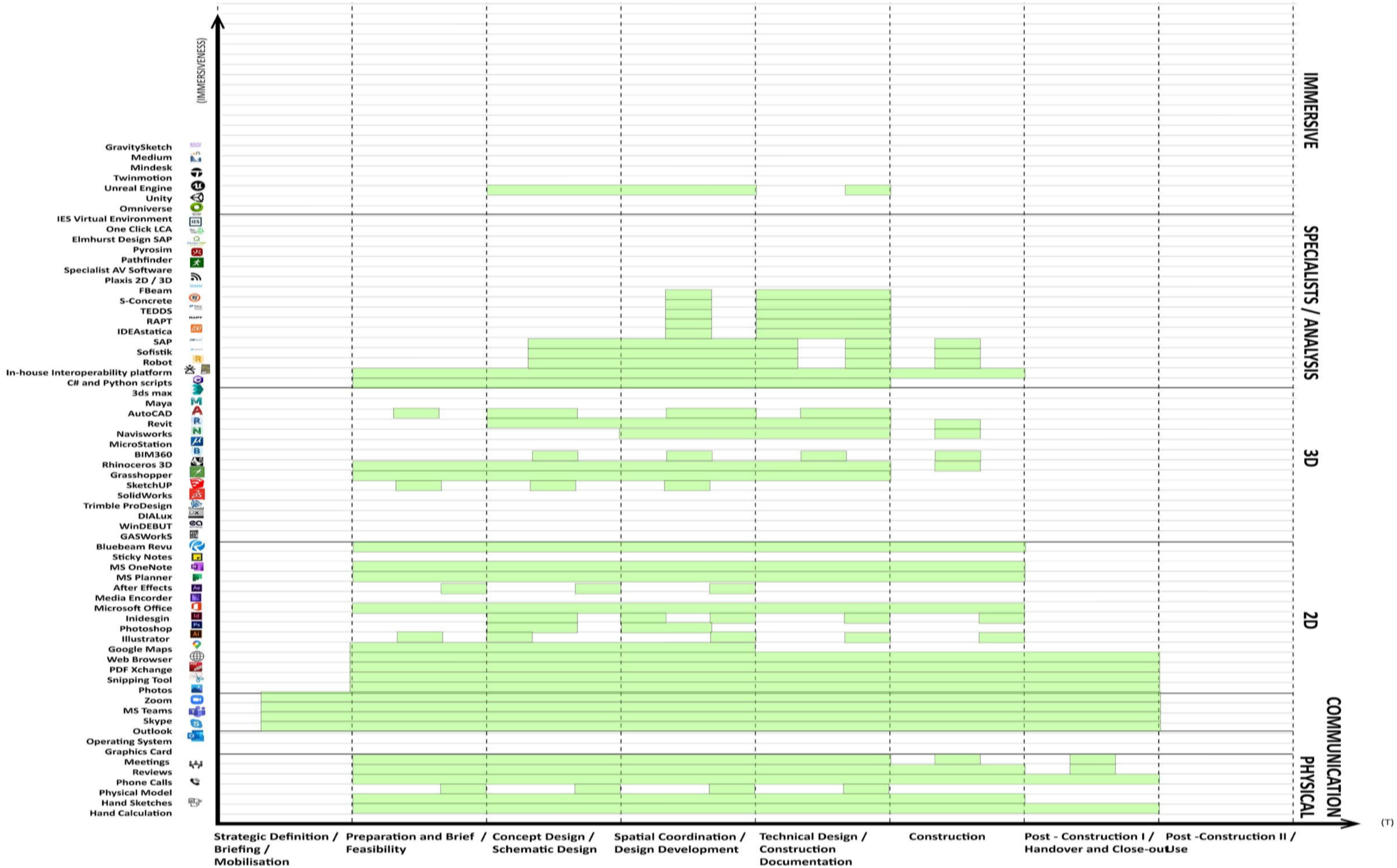
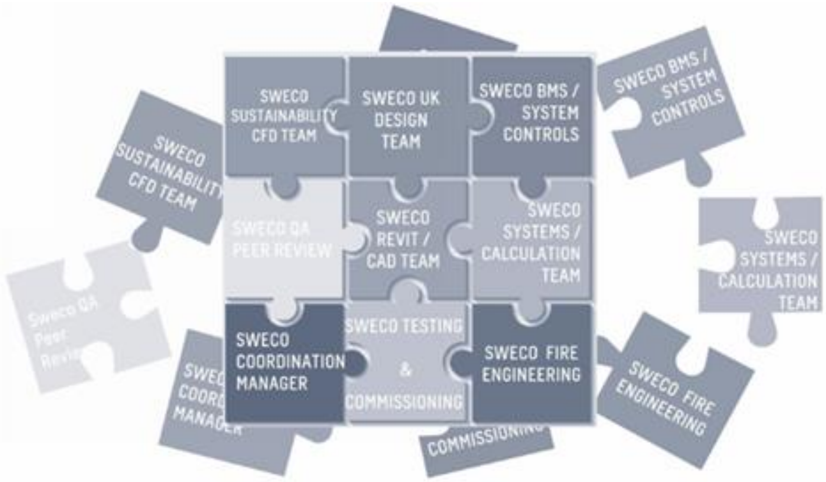


Figure 2.6: Means of communication for Structural Engineering with respect to the project phase.

2.1c Mechanical, Electrical and Public Health Engineering

Mechanical, Electrical, and Public Health engineering, abbreviated as MEP engineering, are three disciplines closely interlinked together in construction projects due to their nature. The mechanical discipline covers topics which include Heating Ventilation Air-Conditioning (HVAC) and gas systems where applicable in the development. The electrical discipline covers electrical power supply and distribution through the development. It also covers lighting, fire detection, emergency voice alarm amongst many other aspects of the design. The public health discipline takes care of the water system in the development as well as all required drainage. The MEP design can also include specialist aspects such as buildings sustainability, Information Technology AudioVisual solutions (ITAV), Vertical Transportation, Fire, and Building Automation Systems.



SWECO, as a consultancy, is able to offer consultancy services for the full range of Building Systems. We have completed in excess of 5,000 projects in the UK and significantly more worldwide and take pride in our ability to work effectively with the entire project team.

MEP systems are an important part of building services and can have many different functions. Typically designed by specialised consultants and contractors, MEP systems can present complex challenges in terms of coordination and detailing. They must satisfy multiple objectives and criteria for design, installation, commissioning, operation, and maintenance. Some of the challenges involved include:

- Spatial coordination; avoiding hard and soft clashes.
- Multiple parts functioning effectively together as a single system.
- Complex installation, testing operation and maintenance procedures.

(https://www.designingbuildings.co.uk/wiki/Mechanical,_electrical_and_plumbing_MEP)

The scope of systems provided include:

Air Conditioning	Gaseous Fire Suppression Systems	Power Generation
Audio Visual Systems	Gas Supplies & Distribution	Public Access
Automatic Controls	Heating Plant & Equipment	Public Health Installation
Building Management System	Hoists	Refrigeration Plant
Car Park Services	Information Technology	Refuse Collection & Disposal
Cooling Plant & Equipment	Kitchen Services	Solar Control Systems
Communication Systems	Laboratory Services	Sprinkler Installation

Combined Heat & Power Plant	Lighting	Standby Generation
Control Systems	Lighting Protection	Thermal Distribution
Data Transmission	Mechanical & Smoke Ventilation	Turntables
Domestic Water Services	Mechanical Gas Systems	UPS
Electronic Security	Natural Ventilation	Utilities
Electrical Services	Noise Evaluation & Control	Water Treatment
Fire Detection & Alarm Systems	Pneumatic Tube Conveyancing Systems	Vertical Transportation

SWECO Buildings (MEP)

The Buildings team has 150 staff. This includes our MEP engineers as well as our specialist departments of Structural, Fire, Security, Networks, Environmental and Vertical Transportation. We also have 53 no. Chartered [CIBSE] Engineers within our main office. Our main office recently participated in a pilot scheme alongside the Building Research Establishment to become a BREEAM Associate company [BREEAM]. It required that 40 no. of our engineers participated in training and awareness of wider sustainability knowledge that would be beneficial to clients and their business. These 40 engineers were then required to pass an online exam before Sweco could be awarded our Associate status. The chart below (Figure 2.7) highlights the organizational structure within Sweco buildings, and it should be inline with a similarly disciplined organization in the UK.

STAFF SPILT	NOS.
DIRECTOR OF BUILDINGS	1
DIRECTORS	7
ASSOCIATES	15
EXECUTIVE ENGINEERS	14
PROJECT ENGINEERS	21
SENIOR ENGINEERS GRADE 1	28
SENIOR ENGINEERS GRADE 2/3	21
ASSISTANT ENGINEERS / GRADUATES	20
ADMIN / OTHER	23

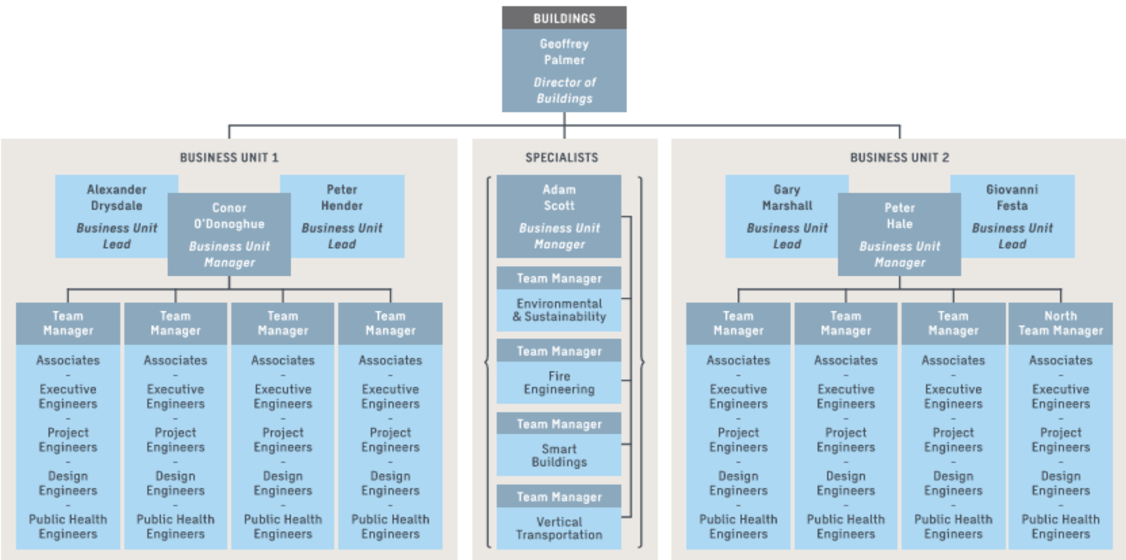


Figure 2.7: Sweco's Buildings Structure

The Design Approach

The following diagram (Figure 2.8) demonstrates the disciplines applied during the development design for MEP engineering. The chart shows that we see ourselves as integrated into a process that involves many other designers and stakeholders, and that we appreciate the need to communicate effectively with external parties at all stages of the process.

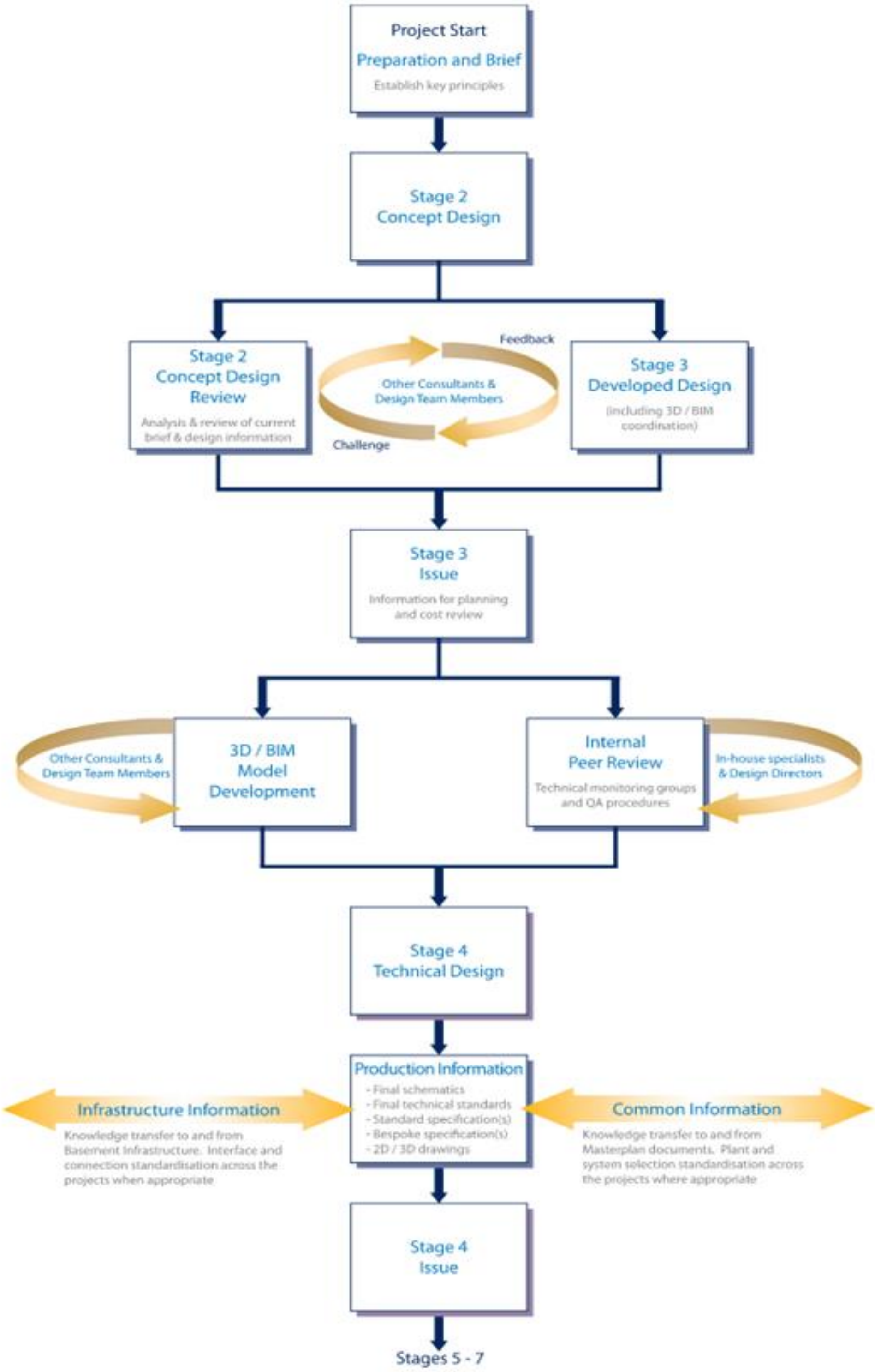


Figure 2.8: Workflow for MEP design.

RECONFIRMING THE BRIEF

As early as is practicable in the project, Sweco review the existing engineering services brief. This document contains:

- Technical design parameters
- Outline proposed concept solutions
- Performance targets
- Solutions based on the principles of the project vision.

This brief would be regularly reviewed with the client / project manager and design team as the project progresses in order to:

- Incorporate the learning and lessons learnt on other recent projects
- Record design development
- Monitor changes in requirements
- Demonstrate the achievement of the Client's objectives
- Enhance communication between team members.

ENGINEERING STUDIES

We regularly undertake engineering services studies during the briefing stage. We would expect to further review:

- Interfaces with infrastructure and district heating system services
- Power loadings and energy demands
- Applying low carbon technologies
- Flexibility and future proofing
- Prefabrication and design for manufacturing and assembly (DfMA)
- Environmental and energy issues
- Part L analysis as part of the building's energy strategy
- Review of fire safety engineering and integration into MEP design.

The results of ongoing studies are integrated into the engineering services brief. Further on in the detailed design process, our team members will form dedicated design teams allocated to each architect. **Whilst each building will be serviced by a dedicated design team, there will be a level of common information and resource, such as 3D CAD/BIM, that can be shared appropriately across all buildings and basement design. This will assist us in delivering an efficient service and focusing on coordination with the unique architecture of each building.**

The diagram also demonstrates that we operate a robust quality system controlling and monitoring our work. Company-wide checks are made that consist of internal peer design reviews (Technical Monitoring Group, or TMG reviews), which are chaired by one of the other Directors. The TMG process is part of our BS EN ISO 9001 quality system and provides an opportunity for a fresh review of our work by senior members of staff not involved with the project.

TMG reviews cover all aspects of SWECO's work including compliance with the brief, concept, design, technical quality, safety, energy efficiency and cost. Constructive feedback to be an important aspect of this system.

MANAGEMENT OF INTERFACES

There are a number of interfaces between each scope for the engineering services and with the greater design team. SWECO recommends developing a detailed Building Services Research and Information Association [BSRIA] style interface and responsibility matrix, especially in view of the complexity of interfaces between building and infrastructure. It would be used to identify lead and support roles in relation to the input and coordination of the building MEP design with the rest of the design team including:

- Building Research Establishment Environmental Assessment Method [BREEAM] for retail
- Site wide infrastructure and utilities capacities
- Basement space planning
- Traffic and logistic planners
- Landscaping and public realm ventilation openings to spaces below ground
- Rainwater attenuation and storage
- Sub-slab drainage
- Riser and distribution zoning
- Low and zero carbon systems (LZC) integration
- 3D model / building information modelling (BIM)
- Construction programme and cost plan.

VALUE ENGINEERING

SWECO is committed to value engineering and strives actively in conjunction with other members of the Design Team, to achieve cost effective solutions in response to the Client's needs. We would propose reviews at several stages in design development.

PRODUCTION INFORMATION

The Project Leader will be responsible for the management of the production information process. Their duties include the preparation of drawings, document schedules and to monitor progress against programme dates. In conjunction with the Group Director, the Project Leader would allocate the required resources to the project.

SWECO's Design Approach/Methodology

Integrated Management System (IMS):

The IMS is maintained by a dedicated team providing regular reviews to ensure that it remains effective in terms of current business activity and future objectives

SWECO's Integrated Management System (IMS) is certified to:

- ISO 9001:2015
- ISO 14001:2015
- OHSAS 18001:2007

QUALITY ASSURANCE

Each project has a Project Management Plan (PMP) that details the specific IMS requirements for that project. As part of these requirements, Technical Monitoring Group (TMG) reviews are held at key stages of the project with senior members of staff from other design groups who carry out a detailed technical review of the proposals for the project. These TMGs review all aspects of Sweco's work including compliance with the Client's brief, concept, design, technical quality, safety, energy efficiency and cost.

ENVIRONMENTAL MANAGEMENT

SWECO's Environmental Management System (EMS) operates within the IMS and provides a structure for the management of our environmental impact in both our office and operational activities and our design services.

Our environmental and sustainability policy statement ensures SWECO plays its part in ensuring a better environment and a more equitable and secure future.

HEALTH AND SAFETY

A full-time health and safety team addresses the health and safety responsibilities of the company and ensuring compliance and implementation of the Group's policy. Each regional office has an appointed Health and Safety Representative, a structure which ensures that a consistent approach to health and safety is cascaded and applied.

A positive health and safety culture is embedded in all the work that we undertake. All new staff attend both a company and local induction where the company's Health and Safety Policy and general health and safety issues are introduced. This ensures that the company's positive attitude and approach towards health and safety is delivered to new starters in a consistent and timely manner.

CONSTRUCTION (DESIGN AND MANAGEMENT) REGULATIONS 2015

All engineers in SWECO understand their duties as Designers required under CDM 2015. We have undertaken the role of Principal Designer where engineering is clearly the lead discipline for a project. Regular updates for our staff are made through the e-learning modules on the SWECO Intranet which cover CDM, HSQE and other technical and commercial topics.

MEP - Tool relationship

The figure above showcases the tools that are commonly used by MEP consultants on typical projects. It highlights on which design stages the tool is typically used and for how long its usability would extend.

Project Specific Management

A typical project would have a designated project manager and a project director. All project related matters would have to be reviewed and approved by both individuals.

Diagrammatic Drawings:

Diagrammatic drawings are usually used in the form of hand sketches and mark-ups during various design stages. For instance, during the concept stage, these would be used to provide a basic representation of the design intent to the client and the wider design team. On later stages, sketches would typically be issued to pick up minor design changes or updates or in response to raised requests for information (RFIs).

Presentation

Digital presentations, generally using PowerPoint, would take place during various stages in order to present design development, options, or stage issues. These presentations would typically take place within a physical meeting. However, due to the current pandemic restrictions, video conference tools have been used to conduct these presentations. These presentations would typically include the issue report, appended by all drawings, and each discipline representative would present their design intent to the client with room for questions when required. If the presentation is to show progress or provide design options, then this is typically conducted by the lead engineer demonstrating the pros and cons of each approach and highlighting the consultant's preferred option to aid the client's decision.

Drawing Submissions

Depending on the type of the project, the deliverables of the MEP team are submitted via an agreed platform. In many cases, and especially during the early stages of the design, packages tend to be issued via emails. However, on many instances, specialised platforms, such as Asite and Aconex, are brought onboard for drawings submissions, reviews, and approvals. These platforms also allow the facility to raise issues/RFIs and other means of communications.

3D sketch / Spatial Organization

3D modelling tools are used to assess 3D model updates shared by the wider design team. These participants would include the architectural and the structural teams as well as all disciplines within the MEP team should the project be large enough to require such a split. 3D sketches are typically done using sketching software when required. However, it is more common to model the design directly onto the BIM software and progress the design as the project develops. This also facilitates the frequent model exchange between the design teams that shows progress, aids coordination and allows early identification of potential design risks or conflicts such as clashes. The implemented 3D models also become a source for 2D line drawings including plans, sections, elevations, perspectives, as well as the source of photo-realistic renderings for the purpose of presentations / reports if required by the project.

Simulations

As part of the MEP design exercise, various specialist simulation software are used to validate and assess the design intent. Being the multidisciplinary field that it is, these software form an important role in the design workflow. For instance, electrical engineers would use software to assess the electrical distribution within a development as well as the lighting requirements in line with the relevant standards. Alternatively, certain internally developed tools can be used to supplement and validate the intended design especially when no reliable specialist tools are available in the market for such specific needs.

Visualisation

Visualisation can be conceptual drawings, photo-realistic images or virtual reality experiences. Visualisation helps all disciplines to understand the overall look of the project - this includes programs, scales, materiality, structural espouse, facade design etc. Visualisation also plays an important role during the design development as it allows adequate special coordination and appreciation of requirements by each discipline and various design teams. The level of detail provided for the visualization exercise would depend on the nature of the project and the design stage which this is implemented on.

VR

Virtual Reality technology allows all disciplines to evaluate the project immersively for both internal and external reviews. Depending on the project budget, scale and presentation locations, 360 still images with standalone headsets or real-time image sequence with headsets plus tracking system are used to review contents. Depending on the project needs, VR can be used to provide a realistic visualization. This can be in order to advertise the end product be it a flat or an office. It can also be used to investigate specific design elements such as MEP cupboards and ensure that the end product is satisfactory to the client as well as the wider design team.

Current Communication Means used in MEP Engineering

In Figure 2.6, the communication means that are employed when developing an MEP design are listed. The horizontal axis represents the phase where each mean is used and the ordinate axis represents the immersiveness level of each mean starting from the 3D model, continuing with advanced BIM software such as Revit, and ending on immersive representations such as IES Virtual Environment.

2.1d Architectural project life cycle

Finally, the software with respect to disciplines are depicted in the following Figure 2.10.

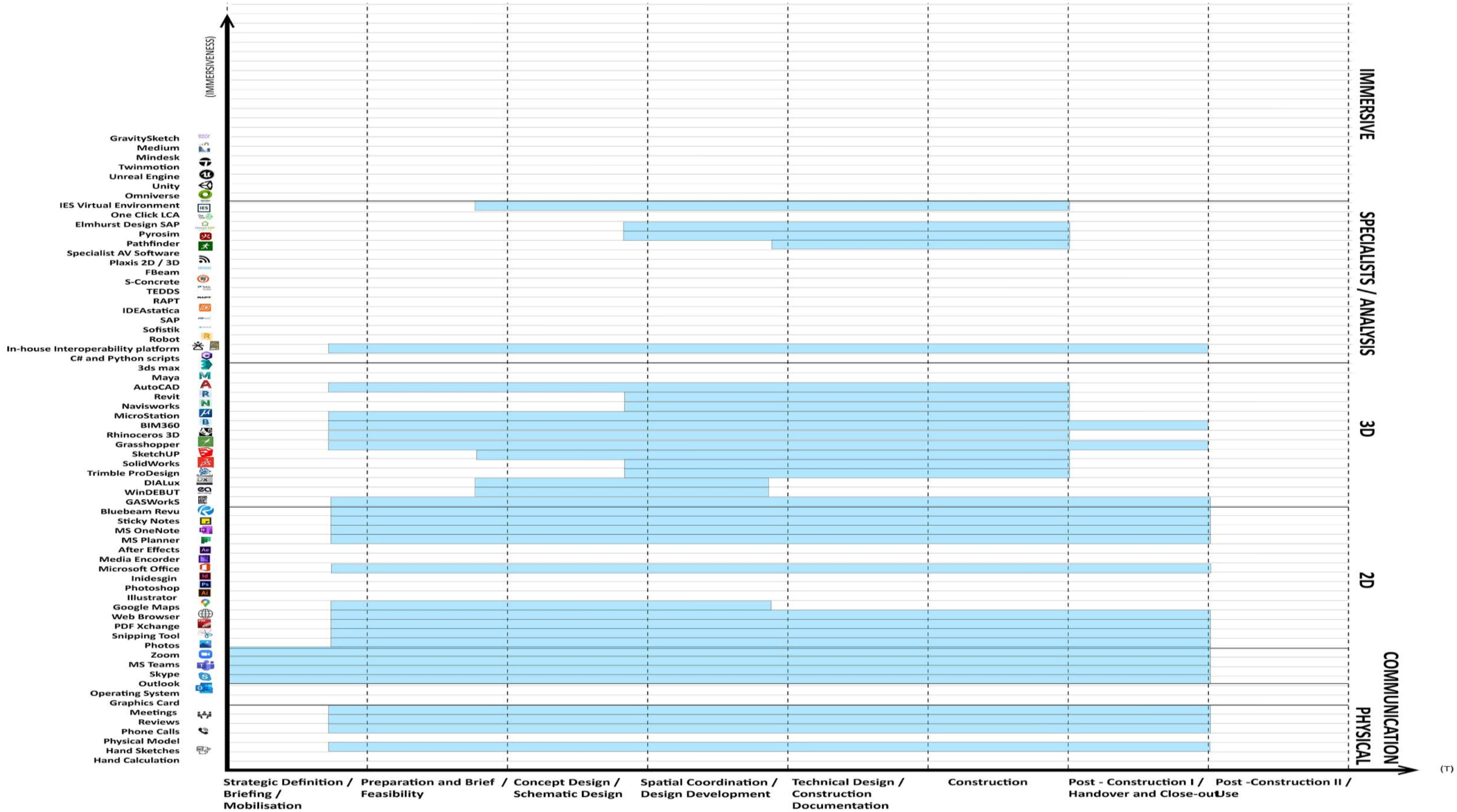


Figure 2.9: Categorization of Software. Abscissa is time denoting in which phase of the Architectural Project a software is used. Originate is Visualization level starting form sketches and mockups and ending to immersive environments.

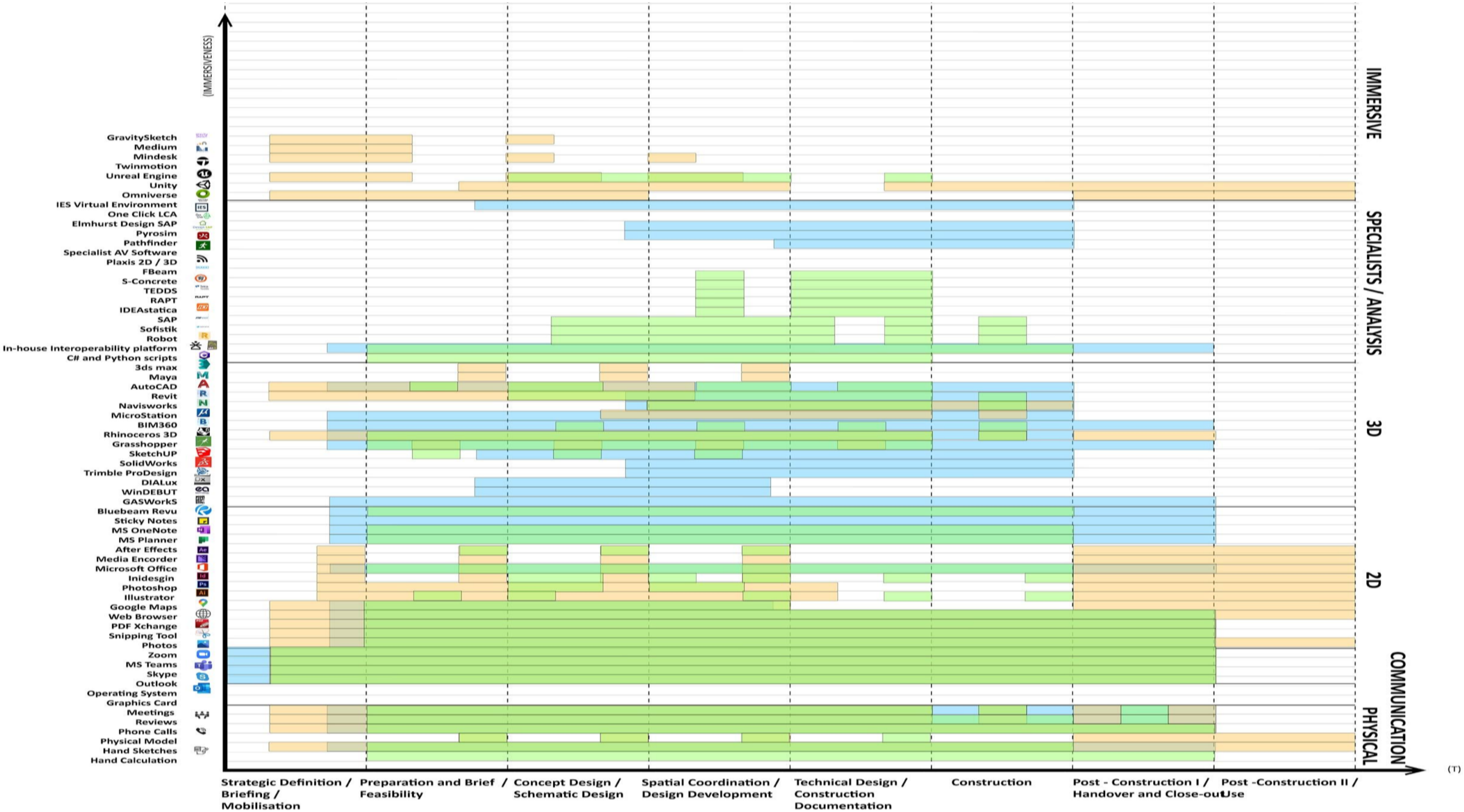


Figure 2.10: Discipline - Tool relationship. Overlaying the 3 diagrams / software distribution map

2.2 Market Analysis: Existing Immersive AEC & Collaboration Tools

In the previous section, we explored responsibilities, obligations and authorships of each discipline from the AEC industry. Depending on project briefs, their design challenges and motivations, not all architectural project incidents would match the way currently BIM functions as each discipline resides in their own project cycle with their preferred tool kits and resources. Each software company provides their own functionality and the business models that are incompatible with other companies' products and platforms. Although there are software applications or systems such as Omniverse to attempt to change this current infrastructure by creating a cloud base system with universal data transitions, the technology is still in the progress of development. In other words, there is no singular space available yet that allows all disciplines to work together coherently.

With the introduction of immersive virtual reality and networked collaboration solutions, it is now possible to view content immersively and photo-realistically, however, there is no such tool available in the market that allows to blend these disciplinary unique perspectives into one - and that helps to dynamically and organically link project data across project phases as well as disciplines.

This section looks into the existing market available tools to highlight currently available features and the use of them.

Examples of the existing market available AEC collaboration tools are analyzed in the following sections. In 2.2.a Project Delivery Tools, an analysis of three important tools are analyzed, namely Revit + BIM 360, Fuzor and Vrex (or the Wild). In 2.2.b Immersive Design Tools, we are describing [Arkio], [Gravity Sketch], and [Mindesk]. Finally, in Section 2.2.c Visualisation Tools (Material updates, real-time environment update, simulations) are described such as TwinMotion for achieving photorealism of Architectural elements in Unreal [TwinMotion], and NVidia Omniverse [Omniverse] (Universal data unit for selected applications)

2.2.a Project Delivery Tools

Revit with BIM 360

Revit with BIM 360 is a suite of cloud based building design and construction management applications that connect data to BIM based workflow. As regards the categorization of software with respect to Figure 2.10 - Categorization of Software, REVIT and BIM360 is allocated across a great span of the time context and it is in the middle with respect to visualization capabilities as it is not an immersive environment (Figure 2.11).

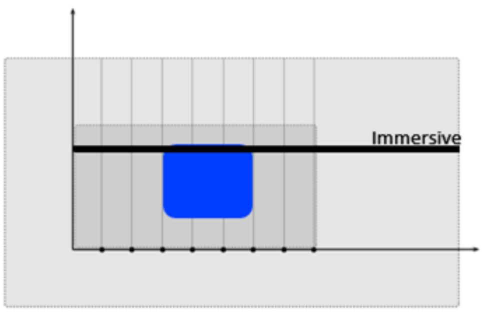


Figure 2.11: BIM360 and Revit is located at the middle project phase, below the immersive curve

The suite includes software designed for documentation, quality and safety control, project management, coordination and constructability, design collaboration and facilities management (Figure 2.12 - BIM and Revit images). Revit and BIM 360 are design and construction software that are designed to coordinate architectural data. In order to review BIM models developed with Revit inside VR with its full potential of the technology, external software applications are required **[Revit], [BIM 360].** The pros and cons of REVIT and BIM360 are overlaid in the following lines.

Pros: 2D from/3D translation with dynamic modification; Single database; Project unique and customisable data families; Preset asset library with parametric components; Analytical tools such as area, energy, structural and solar, 100 digital workflow minimises number of drawings, and Cloud base file management system.

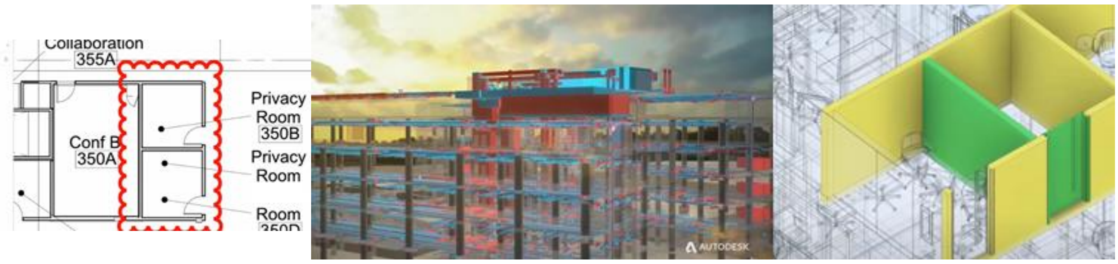


Figure 2.12: BIM360 and REVIT Images from: https://www.autodesk.com/bim-360/

Cons: Data families need to be carefully designed in an early stage of the project development; The system does not include the architectural data from the concept stage if the building is modelled outside the software; Users requires training and specific knowledge to fully be able to implement the software system to architectural projects; External applications are required (or recommended) to explore the full use of VR technology.

Fuzor VR

Fuzor is a virtual design and construction software and it offers a suite of analysis and coordination tools to manage the construction phase of architectural project development. It is located towards the middle-end of the project and it is spanning below and above the immersiveness line as regards (Figure 2.13). The software can load and combine large 3D asset data, point cloud data and project time schedules and can run 4D and 5D simulations (Figure 2.14 - Fuzor images). Users can create construction trailing materials that can be immersively visited by field workers [**Fuzor**].

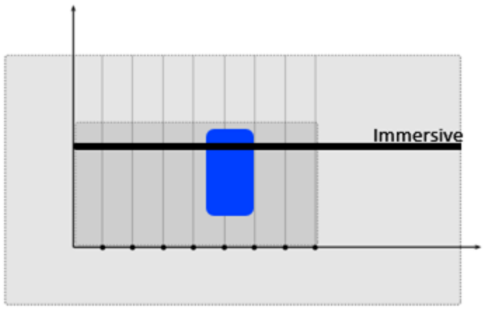


Figure 2.13: Fuzor is located towards the middle-end phase and it spans also above the immersiveness line

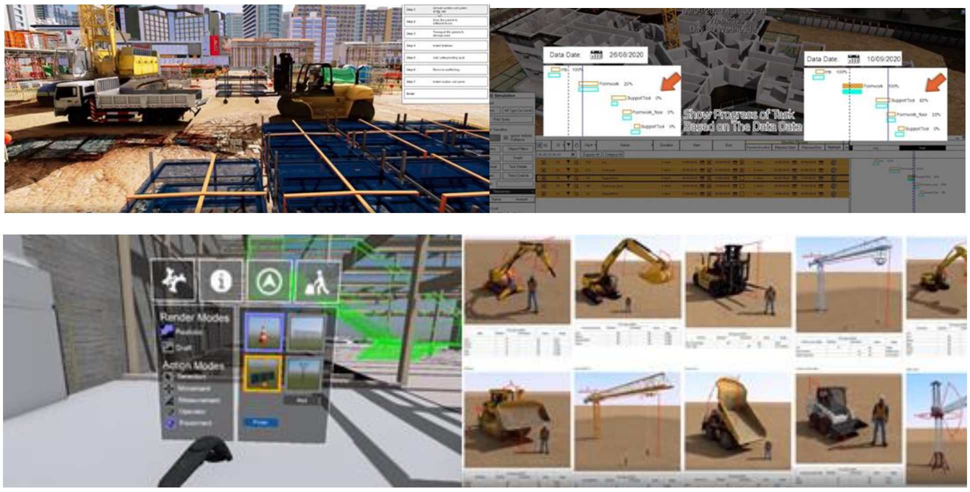


Figure 2.14 - Fuzor images: A multipurpose tool combining BIM and VR elements.

Its Pros are development centered functionality design (for engineers); time and budget management; resource planning; clash analysis; pre-set construction asset libraries; object annotation system;

Training; Multi presence VR with pre-set functionalities such teleport, scaling and commenting. Its Cons are**:** User interface design is not intuitive; and the software target is at the construction and later stage of the project life cycle.

VREX

VREX is a virtual design and construction collaboration platform [VREX] located well above the immersiveness line (Figure 2.15). The software application manages to load a large BIM file and all project members and stakeholders can meet inside the loaded model. The platform offers preset functionalities including teleporting, pointing, selecting objects and commenting on assets by creating and sending Building Collaboration Format (BCF) to the original BIM model (Figure 2.16).

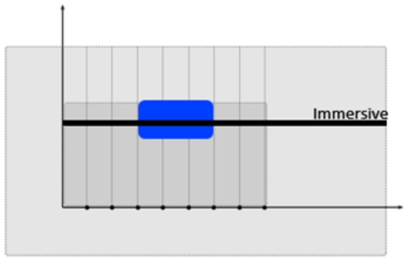


Figure 2.15: VREX is most an immersive software used in the middle phase of the project.

Its pros are User friendliness; Virtual meeting room setup for all members including stakeholders; Communication centered functionality design (for designers and engineers); and Voice to text capabilities. Its cons are basic functionality but not including architectural incidents from an early stage of the project development.

Figure 2.16: VREX collaboration software.Images from: https://www.vrex.no/

2.2.b Immersive Design Tools

Arkio

Arkio is a virtual design and collaboration platform that is made for architects [Arkio]. It is a software mainly for the first design phases of a project (Figure 2.17) The platform offers an original volumetric modelling engine which can be run in real-time with VR headsets and supports Revit data input via their plugins. The software includes intuitive functions for VR environments such as volumetric studies, scaling 3D models, commenting on updates and measurements. Its design and multi-user capabilities can be seen in Figure 2.18. Its pros are: Intuitive UI and platform design and Discipline specific function designs. Its cons are that it only covers an early stage of the project development and the software might not be helpful to other disciplines but architects.

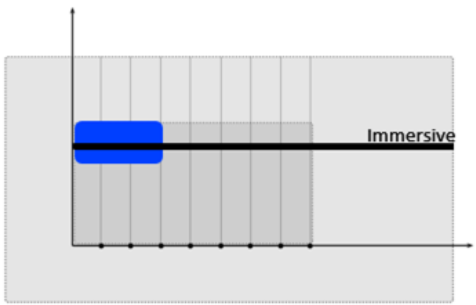


Figure 2.17: Aktio is an immersive software for the first phases of a project

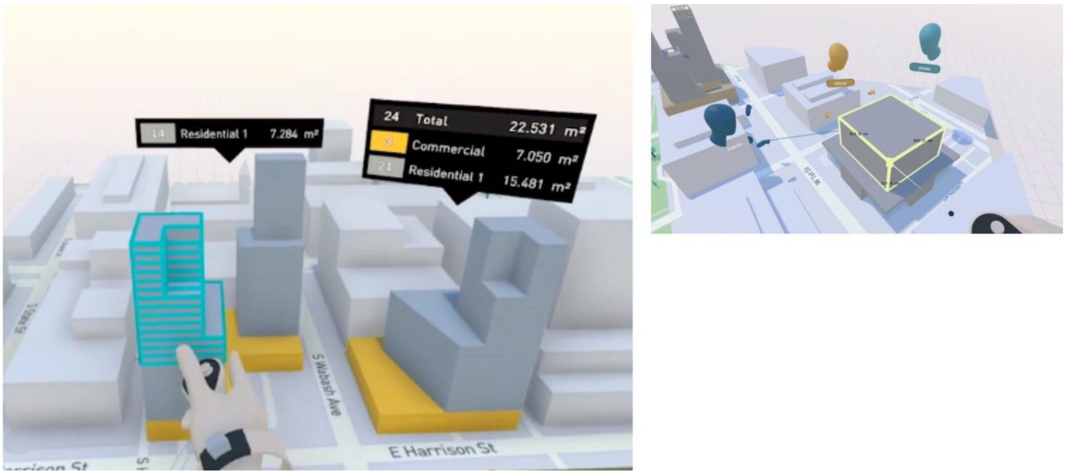


Figure 2.18: Aktio virtual reality interfaces.Images from: https://www.arkio.is/

Gravity Sketch

Gravity Sketch is a design and collaboration platform with a real-time sketching tool [Gravity Sketch]. It is located well above the immersiveness line and it targets for the early stages of the project (Figure 2.19). The platform works across different types of devices including ipads to hand sketch designs (2D drawings output) and VR headsets to immersively sketch and refine the designs inside the virtual reality environment. It also functions as a collaboration platform to review the designs. (Figure 2.20). Its pros are that the platform works with multiple types of devices, it has intuitive transitions from 2D hand sketches to 3D models; and designers can immersively sketch and refine early stage options quickly. Its cons are that the models might lack accuracy and the output won't be technical and it only covers an early stage of the project development and the software might not be helpful to other disciplines but architects.

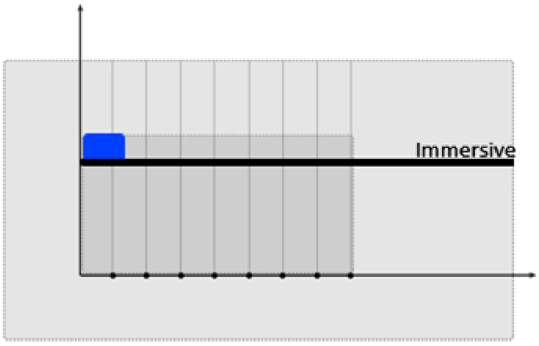


Figure 2.19: Graphivity Sketch is a pure immersive software for the first stages of the project.

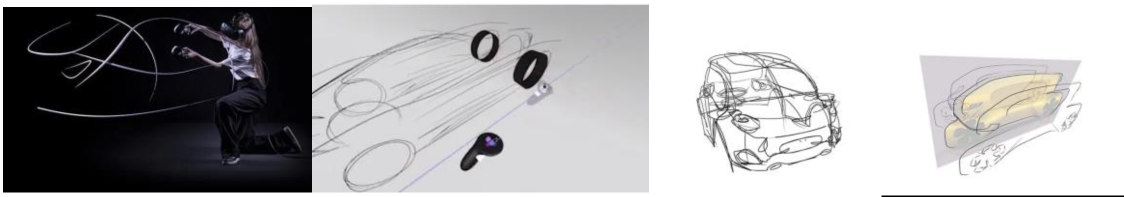


Figure 2.20: Gravity Sketch. Images from: https://www.gravitysketch.com/

Mindesk

Mindesk is a virtual design and collaboration platform. The platform offers live links to CAD software and its associated plugins (Rhino 3D, grasshopper) and a game engine (Unreal Engine 4). Updated CAD data can be reviewed by both the designers and clients immediately and immersive with photo-realistic resolutions [Mindesk]. Its pros is the exploitation of Unreal Live link technology that allows all project members including stakeholders to share and review project updates with high visual qualities; User interface functions are synced with the exiting 3D modelling platform (Rhino3D) and users do not need to learn new commands or UI; and CAD data can be accurately measured and changed inside the VR environment. Its cons are that does not cover an early stage of the project development, where geometry sketching might happen on a flat-screen first; and all metadata capability is controlled entirely through Rhino and its plugins.

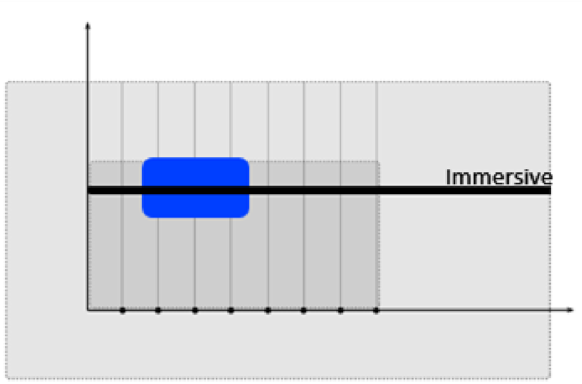


Figure 2.21 Mindesk spans across the immersiveness line for the start-middle of the project.

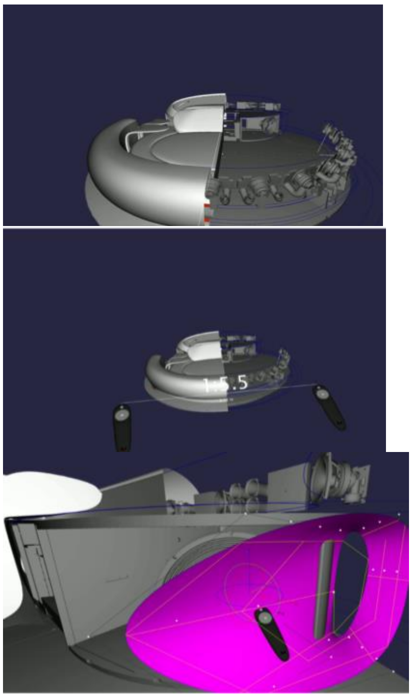


Figure 2.22: Mindesk software usage. Images credit: Zaha Hadid Architects

2.2.c Visualisation Tools

Twinmotion is a real-time immersive 3D architectural visualization tool [Twinmotion] (Figure 2.23, Figure 2.24). The platform supports transforming BIM or CAD models to a real-time experience. The application can be used as interior and exterior reviewing tools by applying materials for both internal and external presentations, and allows to customise the environment design. This includes changing in the sun direction, adding vegetation and people as well as simulating the weather. Its pros are the preset VR functions; the preset asset libraries; and the Live link technology to the Unreal Engine that allows all project members including stakeholders to share and review project updates with high visual qualities. Its cons are

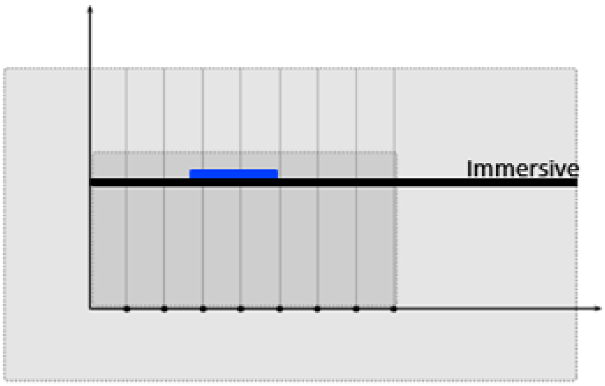


Figure 2.23: Twinmotion is a software for improving immersive visualizations in the middle phase of the project.

that it needs to package as an app before reviewing the content; not including project information for branding and presentation purposes; single player VR mode; and asset libraries are only accessible within the software package.

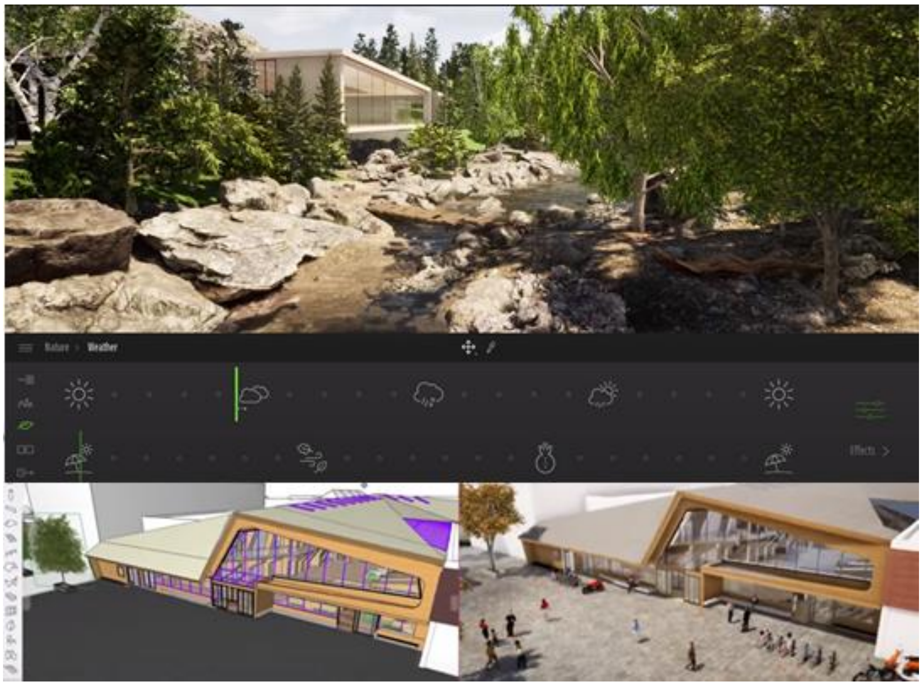


Figure 2.24: Twinmotion software. Images from: https://www.unrealengine.com/en-US/twinmotion

Omniverse Nucleus

Omniverse is a multi-GPU and real-time live collaboration tool between 3D applications and users [Omniverse] (Figure 2.25, Figure 2.26). The platform offers micro services and acts as a hub for multiple 3D applications used in the Entertainment and AEC Industries such as Maya, 3DSMax, Rhino3D, Revit and Unreal Engine 4. The software works with the real-time ray tracing technology that allows users to review the content with realistic lighting simulations. The software offers a private cloud for 3D content, coordinates the assets developed in multiple applications and feeds them into a singular platform. Any changes made inside the individual application will be reflected to a singular scene inside the platform that can be reviewed by all project members in real-time. Its pros are that the assets developed with multiple applications can be reviewed in a singular space in real-time; editor user Interface can be customised; users can create their own applications using the assets inside the singular space; and real-time ray tracing technology allows users to review their contents with high visual quality from an early stage of the design. Its cons are that the platform does not support VR; high spec graphics cards and good memory storage are required; it is not user friendly; and requires programming skills to fully use and adapt to the offered system

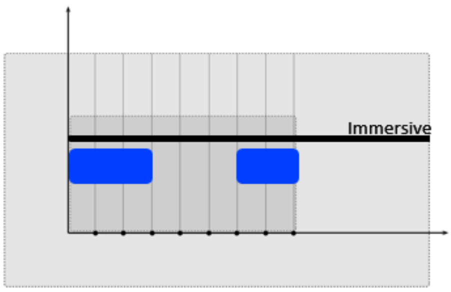


Figure 2.25: Omniverse is located below the immersiveness line and it can be used both in the initial and final phases of the project

Figure 2.26: Photo-realistic visualisation of Leeza SOHO Beijing, designed by Zaha Hadid Architects, visualisation developed using NVIDIA Omniverse collaborating with NVIDIA. Image from: https://www.aecmag.com/technology-mainmenu-35/1985-nvidia-opens-up-omniverse-to-aec

2.3 Discussion

Most of the current market available BIM based project delivery tools offer to translate 3D models from/to 2D. BIM applications allow users to load large data and enable them to converge multiple geometry inputs collected from different disciplines. It provides preset and customisable asset and code libraries that are dedicated to architectural sectors. The project time and cost are managed based on the 3D model updates. External applications or plug-ins help to expand the possibilities to use the singular database such as to read and write geometry data and accessing its metadata. BCF is often used for a communication standard format enabling architects and engineers to communicate with each other using the same language. Yet, in most of the cases, resource management and information registration still need to be executed manually because these are project specific, and the project content or/and project team might require to adapt to the BIM system. The implication of BIM also needs to be noted and approved by all project members and BIM dedicated reports must be submitted in addition to the drawing submissions.

Some architectural practices, including Zaha Hadid Architects, have their own workflow of project development in the concept stages of project development. These 3D models might be developed outside of BIM software. In the case of use of the BIM technology, only the final and selected model will appear in the BIM system. The production executed in the concept stage is generally excluded from the existing BIM ecosystem, hence the current available BIM tools do not cover the entire architectural project life cycle. The user target of BIM rather focuses on its engineering aspects and mid to later stages of the project development.

On the other hand, immersive design tools offer more potential for designers to explore an early stage of the project development. Some applications set their user target to architects and offer discipline specific functions including volumetric studies and area calculations. Comment and markup tools seem to be used by disciplines throughout all project phases and these are therefore commonly included in most of the available AEC tools.

Designers' work involves exploring design options, and they tend to gravitate to tools that allow them to achieve their aim fluidly and within the shortest time. The tools that are used in an early concept stage vary and can be multi-media, can be a hand sketch, digital 2D/3D sketch or cardboard physical models. Some of the available immersive modelling tools allow designers to use multiple types of devices including ipad, desktop, and VR, and 2D output can also be used as references inside the immersive VR environment. This helps architects not to dramatically change their existing workflow or adapt the design process. Yet these immersive modelling tools keep the production quite abstract, devoid of meaningful metadata. Some also allow designers to feed in BIM data, so that the platform can be used as a refining tool. Other immersive modelling tools have live links to the existing CAD software and this enables real-time control and more accurate input. Additionally, Live link to Unreal graphics engine allows all project members including designers, engineers, and stakeholders to review the content updates photo realistically in real-time.

Immersive modelling tools tend to help designers more than engineers, however, the reviewing aspects tend to help across disciplines across project stages. Currently available visualisation tools are often focused to output visual impact of architectural design and the user targets are across user targets who are not familiar with graphics engines and architectural visualisation to setup materials, lighting and environment. Some of these tools also offer to visualise large simulation data which can be used for presentation purposes and these might not be submitted as part of technical reports.

With the latest technology introduced by NVIDIA, multiple content developed by multiple users with different CAD or CGAnimation applications can be reviewed and edited collaboratively in a single platform with photo realistic look. The data is stored in a singular space similar to the BIM systems yet the technology also saves created scenes with an universal format and designers are able to produce their work in the same platform as engineers. The technology is still under development and still requires time to review the content inside the platform, however, it supports live links to game engines so that the content can be reviewed immersive by the connection.

- Architects' responsibilities, obligations and authorities in the Concept stage design development are not included in the current available BIM based project delivery tools.
- There are discipline specific project delivery tools available in the market, however, it does not cover the entire project life cycle, plus it appears to be a self-isolated application that does not function with other disciplines' applications at the same time
- There is an existing platform that converges multiple applications and sees the content within a singular platform with the latest technology, however, project members require technical and programming skills (these are not AEC industry standard skillset) in order to fully utilise the platform
- Immersive design tools can be used across project stages as a photorealistic real-time viewer, however, it does not cover mid to later stages of the project development and these cannot manage database or resources
- Users should have freedom to choose hardware spec and types (OpenXR) and **this also should apply to discipline tools whether these production outputs are physical (hand sketches, physical models) or digital (2d digital sketches or 3D abstract sketches or detailed construction CAD modelling)**
- **PrismArch requires a singular space and the singular persistent database should cover the data produced in all (or any) project stages. The database should be able to be accessed, read and/or written from any stages and by all parties with the relevant access credentials.**

3. PROJECT CASE STUDIES

The four (4) projects found in Table 3.1 were selected to undergo a study and be used as use cases in PrismArch. The main reason for selection was the availability of the content for public dissemination since many other projects were hold under strict non-disclosure agreement (NDA) by the clients of ZH, SWECO and AKT. Each discipline chooses two (2) projects (one for residential and the other one for commercial) to highlight discipline specific incidents that are normally put behind the scenes (i.e.) decision making process before information is shared with other disciplines and clients.

Table 3.1: The Architectural projects under study.

No	Architectural Project	Type	Available content	Lead Partner	Presentation Link
1	Private Residential Villa	Residential	Rhino 3D model Maya Model	ZH	3.1.a Architecture: Private Residential Project / Zaha Hadid Architects
2	One Park Drive	Residential	Revit 2015	Sweco/ AKT	● 3.1.b Structure: ● One Park Drive / AKT II 3.1.c MEP: One Park Drive / Sweco
3	One Thousand Museum	Residential / Commercial	Rhino, Maya, MicroStation	ZH	● 3.2.a Architecture: ● One Thousand Museum / Zaha Hadid Architects
4	Bankside Yards West - Building 3	Commercial	Revit 2019	Sweco/ AKT	3.2.b Structure: Bankside Yards West - Building 3 / AKT II 3.2.c MEP: Bankside Yards West - Building 3 / Sweco

3.1.a CASE STUDY 1: Architecture: Private Residential Villa

Figure 3.1.a.1 Aerial view of the Villa project - photorealistic render

Project Description:

This private residential project with a total site area of **10,000 m²** features a careful organization of spaces which guarantee the level of privacy expected. The project was developed by a team of 12, including Project Directors, Project Associate, Designers and Researchers. The architects were given **2 months to develop the concept** design and submitted the final digital documentation in **June 2020** followed by a client presentation.

Project Directors visited the site to communicate with the clients and to collect site information (Figure 3.1.a.2). The communication during the production was entirely executed in a remote work environment. Video conferences and messaging services were the main collaboration tools within the project team. Throughout the project development, virtual reality technology was used as internal evaluation and external presentation tools. The 360 VR experiences were submitted as part of the final submission. The application of the technology allowed the designers for unprecedented control over the final result, guaranteeing maximum spatial impact.

Bespoke features were designed and developed to enhance specific aspects of the space for different functions: from relaxing moments to vibrant parties and intimate family gatherings. All special activities have dedicated zones which take specialized features into account which are required to give the best service on a day-to-day basis.

Lineal openings along the upper floor allow daylight to filter into the dressing rooms, while maintaining strict privacy to the road and entrance area below. From the road, the building appears as a singular, sculptural shape sitting in the landscape.

The connection between inside and outside is preserved through generous glazing and sheltered outdoor areas, and the interior and exterior designs were merged into a singular sculptural form. The brushed stainless-steel facade highlights the sweeping architectural lines, while giving the building a sleek and futuristic style. Light reflects and glitters on the facade, giving the impression of stepping into a sculpture which hovers above the ground. A spatial transition between climates and landscapes with their accompanying sounds and smells is central to the balance between architecture and the interaction of sun, winds, water, sky and the ground.

The hygiene aspect has been developed following expert guidelines, using ultraviolet lamps for disinfection, self-cleaning finishes, and spaces organized in such a way that the dedicated staff can work in order not to contaminate the main users' spaces.

Incidents:

This case study only covers the concept stage of the entire architectural project cycle and there were no significant correspondence actions delivered between the architects and other disciplines for this specific example. This section, therefore, can be seen as a showcase of pure architectural design development and service executed by an architectural design team. The process of producing design options, evaluating and amending the options, and coordinating programmes and circulations will be the main focus of the discussion in this section. The responsibilities of architects were also to form the project-brief collaboratively with the clients and to propose the best possible solutions that match the clients' requirements (*figure 3.1.a.2*). Although the contract between the architects and the clients was officially signed in May, the production team was on board from one month earlier than the date in the duration of 2 weeks.

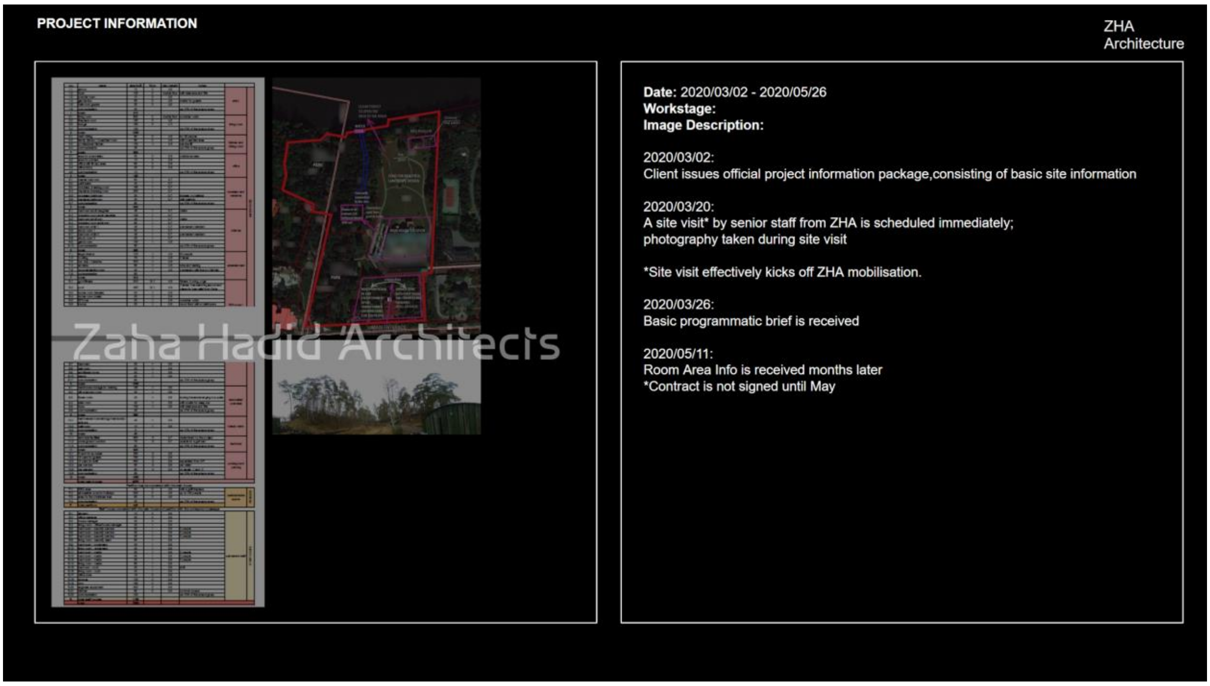


Figure 3.1.a.2 Collection of site data and client requirements

Within the 2-month design development period, 3D site models were prepared to understand the site landscape and to outline the initial design constraints to decide the building location in an open site, identifying private, public, circulation and landscape areas. The site model was also used as the base template for the master 3D model. The hand sketches (*figure 3.1.a.3*) and photos taken by the project director at the site was also used as a site analysis tool. Volume studies, spatial organisation and programmes drove the designers to brainstorm the circulation concepts. Material, cultural and aesthetic research was done spontaneously throughout the exercise by researchers corresponding to the clients' preferences. The project team had three 3D designers to produce architectural geometries. Each member worked individually using their own work environment (software, PC spec, folder structure etc) to produce several massing options. The project team produced a total number of 25 massing options, initially starting from 10 options, and selecting one building and one landscape massing option followed by 3 sub selected building options. Daily bases reviews were organized between the 3D modellers and the project directors

Figure 3.1.a.3 Hand sketches made by the project director

As each 3D designer has their own preference in their work environment, the project team decided to keep the reviewing format in different 3D modelling software consistent by setting the similar geometry materials, view modes and render modes (i.e. artifacts, white clay). For a quick update, the 3D designers used screenshots and as the design has more resolutions, consistent render modes were used within the team.

The designers gave unique names for each option. “Vertical”, “Palazzo”, “Loops”, “Tetris”, “Disks”, “Cube Blend”, “Cube Stretched” were names used for the building (Figure 3.1.a.4), and “Double Pivot”, “Techno”, “Vectors”, and “Pixel” for the landscape (Figure 3.1.a.5). Designers used these names in the file name with dates in their production folder (i.e. 200515_Loops.mb, 200518_strands.mb). These names were also commonly used in design reviews with the project director.

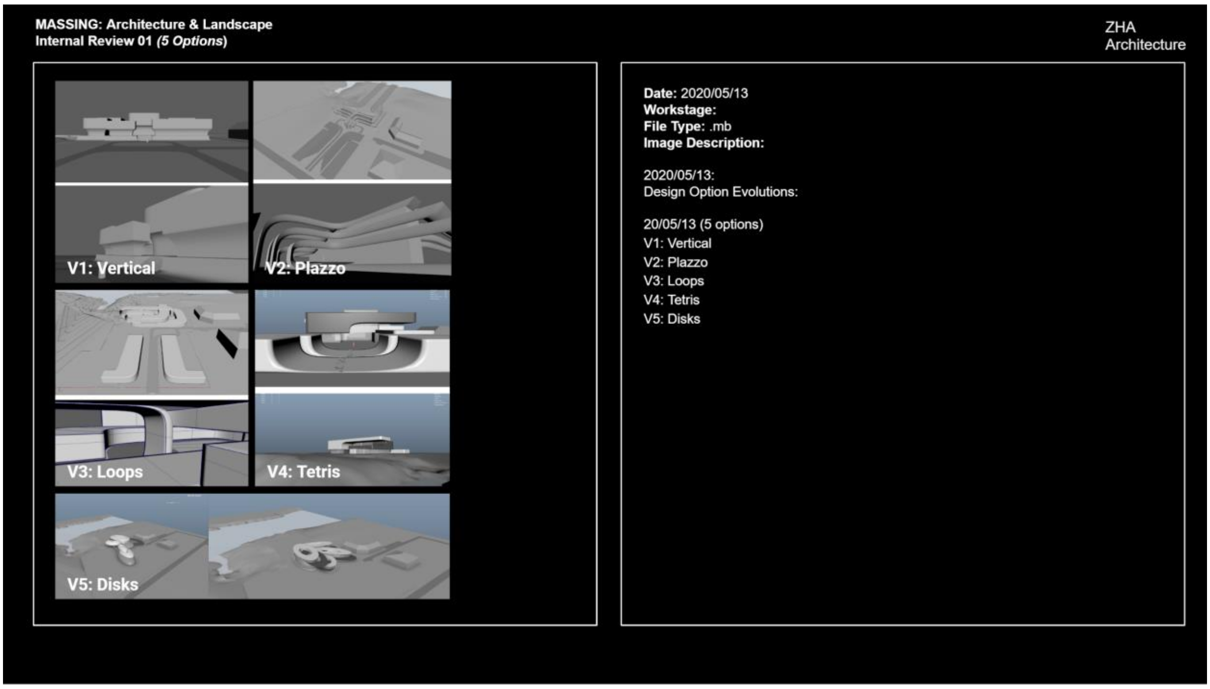


Figure 3.1.a.4 Massing options explored by 3D designers (internal review)

The selected geometry option was completed by stitching the three designers’ input and the data was compiled into one master 3D model file format (Figure 3.1.a.6). The project team added more resolution to the 3D model by using it as a base of the interior model (Figure 3.1.a.7). Material references made earlier were often used to make decisions on interior and facade designs and commun (Figure 3.1.8). The reviewed material outcome was documented and used as materials for marnication with external render companies to produce photo-realistic visuals of the project (Figure 3.1.a.9).

Figure 3.1.a.5 Masterplan and landscape design explored by the 3D designers

ZHA team also directed a narrative for the 360 VR application (Figure 3.1.a.10). A document with collages and mark-ups were produced to share ideas about user interface. The project team managed to match the representation styles experienced inside VR including colour themes, font etc, to the rest of the presentation.

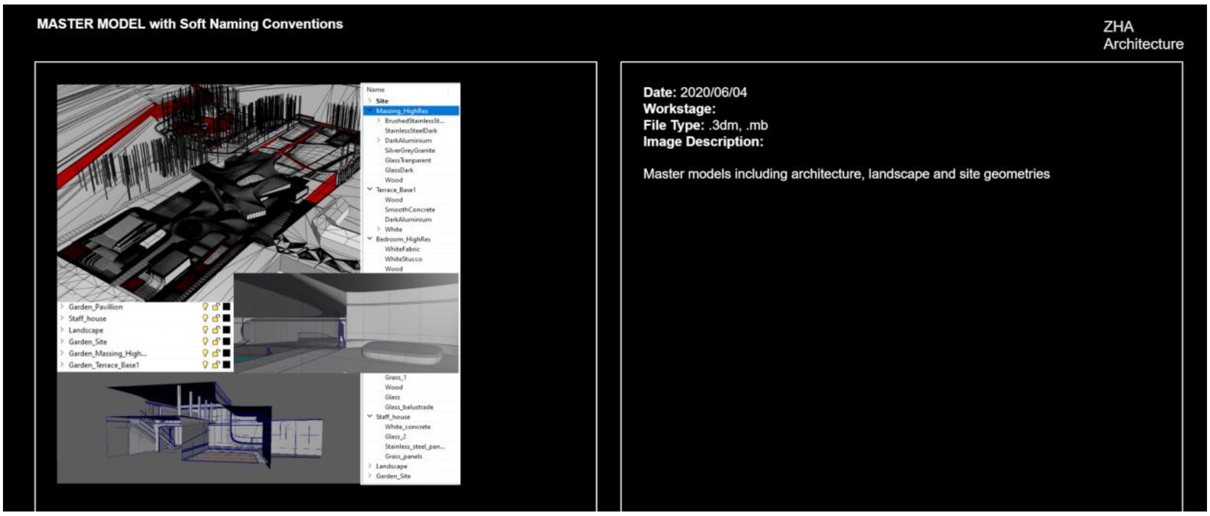


Figure 3.1.a.6 Early-stage master model with soft naming conventions for the 3D elements

Diagrammatic floor plans and sections were made from the same master 3D models (Figure 3.1.a.11). Zones and their names were highlighted in different colours to show the hierarchies of the architectural programmes (Figure 3.1.a.12). The selected drawings and rendered images were collected and laid out in the order of the project narrative and in an order of how the project director presents the concept to the client in the final presentation (Figure 3.1.a.13). The presentation documents had versioning depending on the versions of the drawing and image outputs. The overall points of the collaboration were as follows.

- Design source is mixed-media and mixed-use (i.e.) 3D site model + hand sketches + site photos taken in site visits, 3D sketches + material image references + clients' cultural references
- There was no common work tools across the project team and work output was stitched together after individual production loop
- Setting up a common parameter for view modes synced designers output during versioning

- Having unique version names helped internal communications
- Setting up a master project file synced designers output after the final decision was made
- Commenting and markups for external collaborators are only possible after having an internally approved design output

Figure 3.1.a.7 Interior design developed by 3D designers

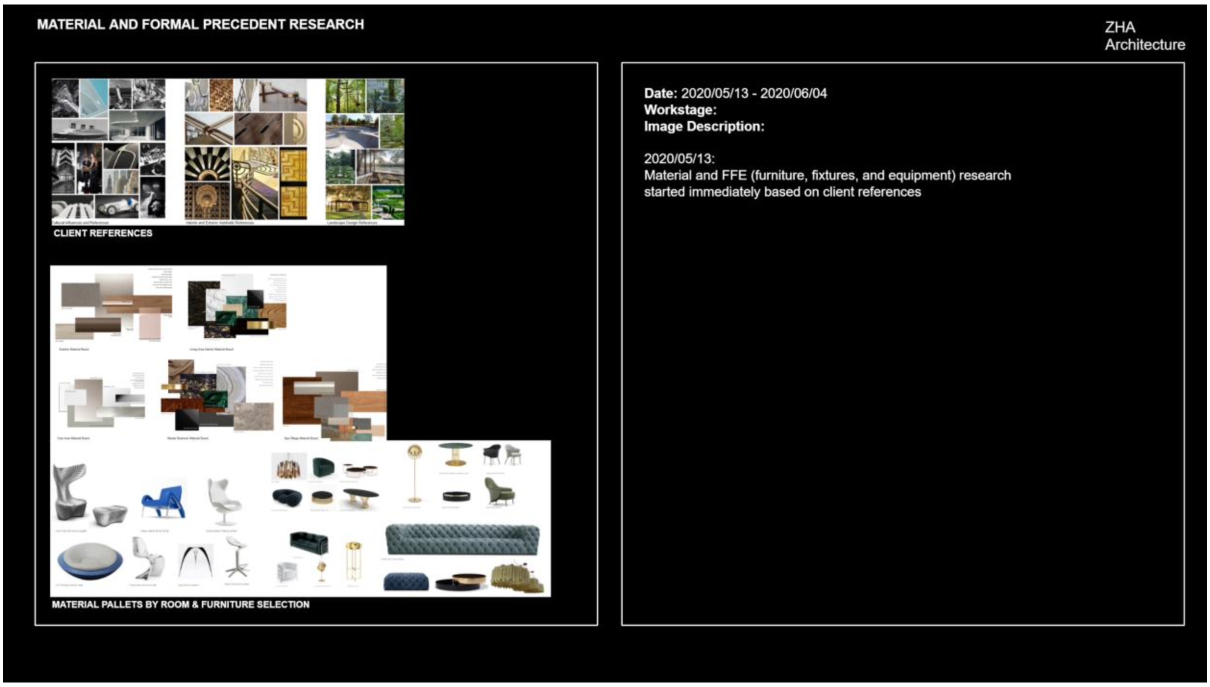


Figure 3.1.a.8 Material references chosen by contributors from Interior team

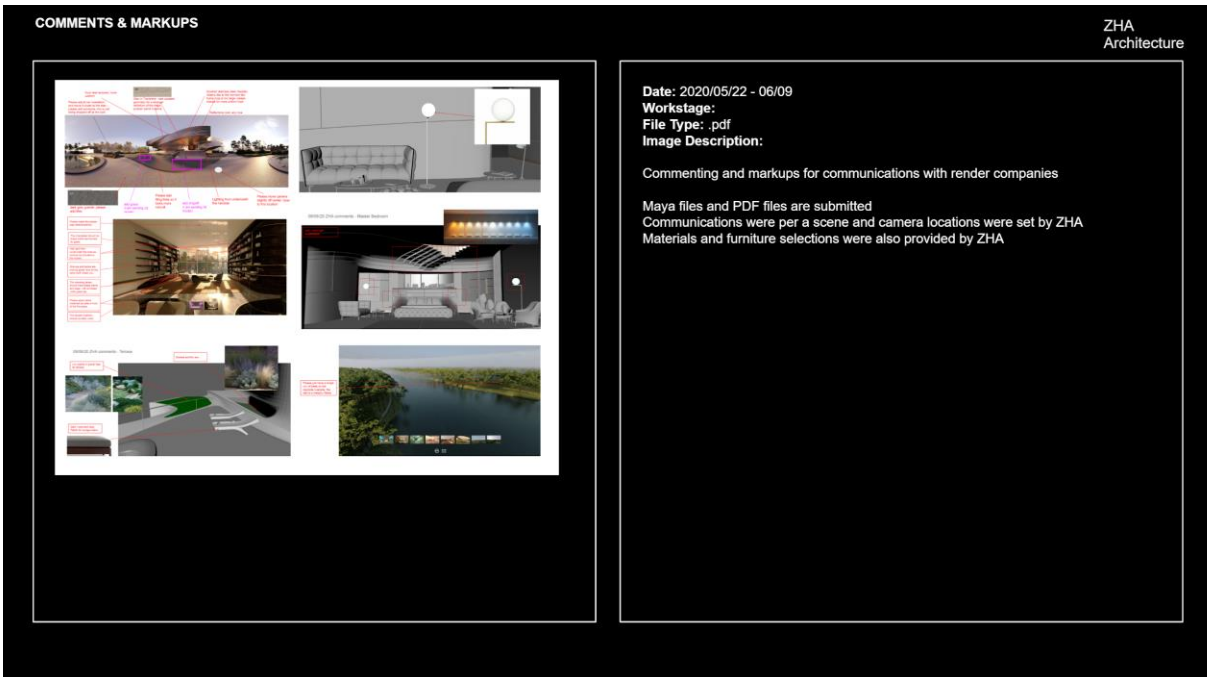


Figure 3.1.a.9 Mark-ups used to communication with an external render company

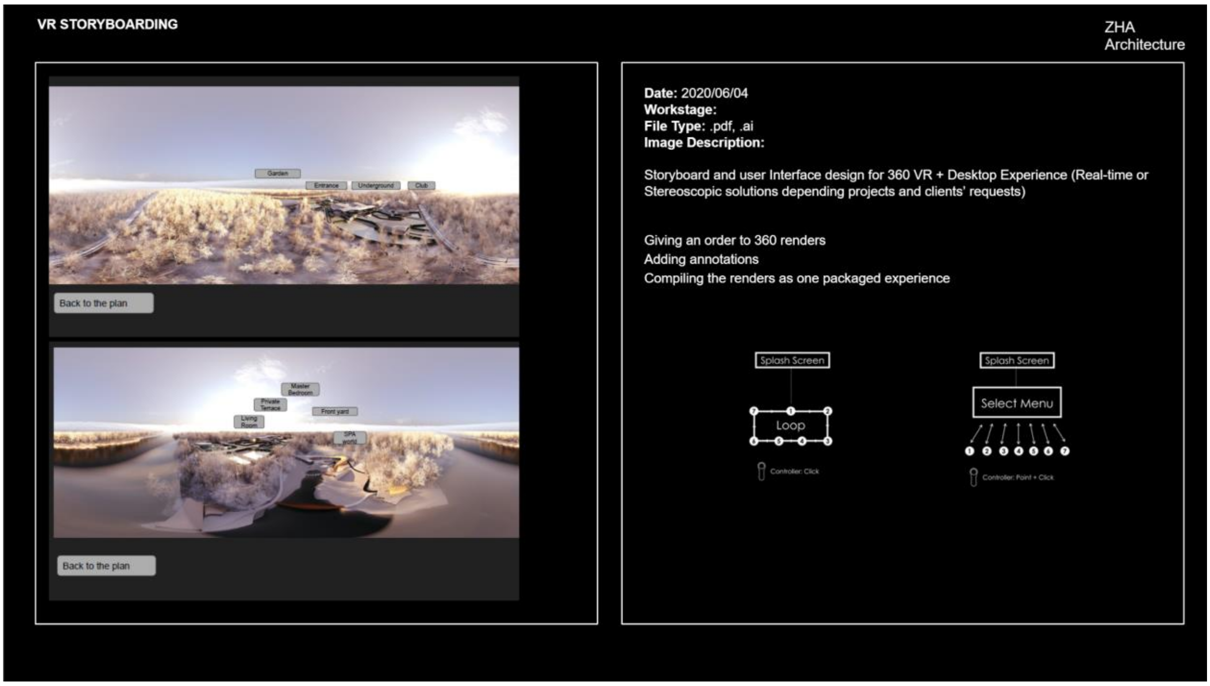


Figure 3.1.a.10 User experience and interface design for an in-house stereoscopic 360 VR application

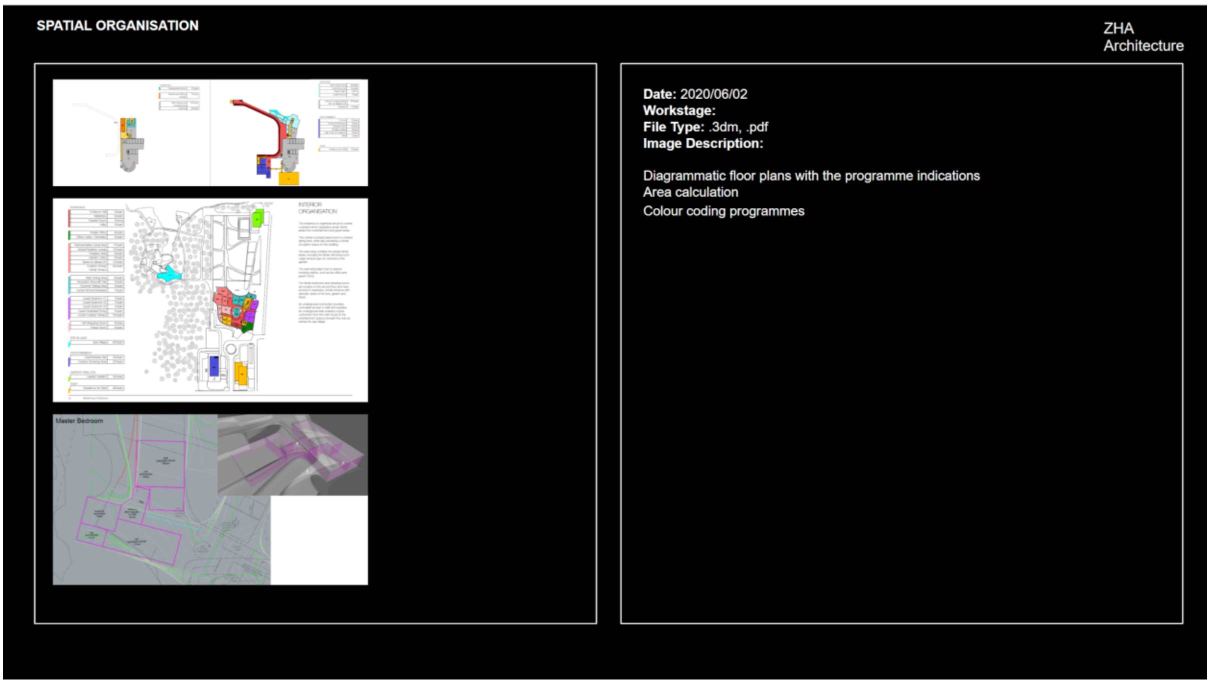


Figure 3.1.a.11 Colour coded plan diagrams showing programmatic adjacencies and floor areas, and volumetric program arrangements

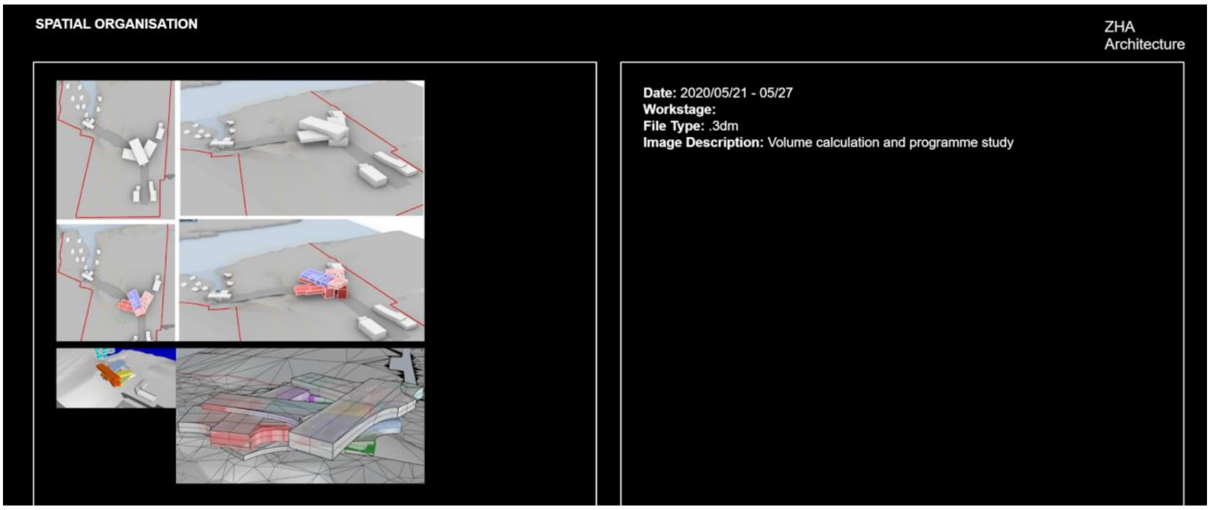


Figure 3.1.a.12 Volumetric and spatial organization studies explored by the 3D designers.

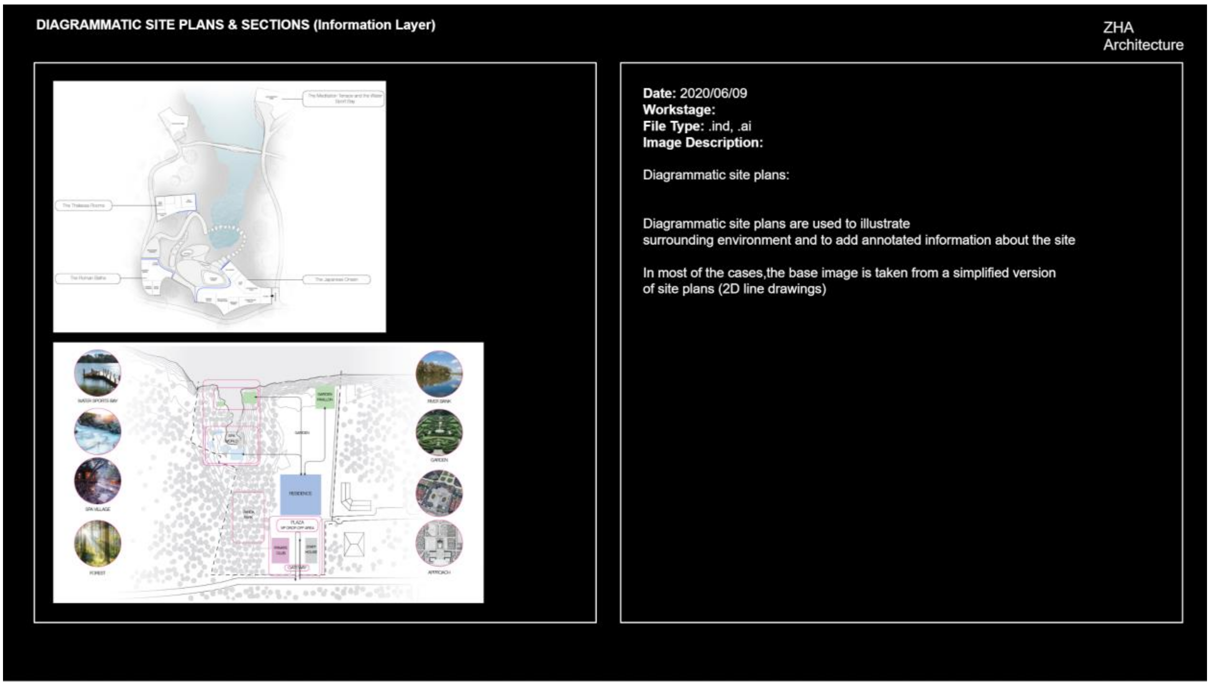


Figure 3.1.a.13 Diagrammatic site plan and colour coded and visual information layers on top

CS1 ZHA	PROJECT INFORMATION	MANAGEMENT	COMMUNICATION: HANDSKETCHES	COMMUNICATION:MARK-UPS	MASTER MODEL	3D SKETCH	STRUCTURAL ANALYSIS	SPATIAL ORGANISATION	DIAGRAMMATIC PLANS, SECTIONS & ELEVATIONS	INTERNAL DESGIN REVIEWS	EXTERNAL PRESENTATION	PHYSICAL & MOCKUP MODELS	SUBMISSIONS
			SITE VISIT: 2020/03/09 - 12										
Month 01	NDA: 2020/03/22	Deliverbles_ recieved from PM: 2020/03/02											
	Recieved Client Brief: 2020/03/26												
	LOI: 2020/03/26												
Month 02			VIDEO CONFERENCE (Zoom): 2020/04/11										
Month 03				LANDSCAPE: 2020/05/13									
		Deliverbles_received room area info: 2020/05/11	MESSAGING SERVICE (WhatsApp): 2020/05/11	ARCHITECTURAL&INTERIOR: 2020/05/13		Architecture & Landscape :2020/05/13-15							PROJECT START: 2020/05/11
				CULTURAL: 2020/05/14									
	Invoice: 20/05/20				SITE STUDY (Modelling) :20/05/07	Architecture & Landscape: 20/05/21 - 25		CIRCULATION :2020/05/21 - 06/02					
					SITE VISIT :20/05/11								
	LOI: 2020/05/20		Communications with render companies: 2020/05/22 - 06/09										
	LOI: 2020/05/25		HAND SKETCHES: 2020/05/25 - 27										
				MATERIAL&FURNITURE: 2020/06/01	MASTER MODEL_soft naming conventions: 2020/06/04		SPATIAL ORGANISATION :2020/06/02				line drawings: 2020/06/02 - 10	DOCUMENTATION: 2020/06/02 - 10	
Month 04	NDA: 2020/06/12								VR STORYBOARDING: 2020/06/09	Inhouse renderings: 2020/06/09	Information layer: 2020/06/09		DIGITAL SUBMISSION :2020/06/11
										Outsource renderings: 2020/06/10			
	Invoice: 20/06/15												PRESENTATION :2020/06/15
													CLIENT FEEDBACK :2020/06/29

Figure 3.1.a.14._Project Incidents

Higher resolution / excel sheet

3.1.b CASE STUDY 2a: Structure: One Park Drive / AKT II

Project Description:

Part of the Wood Wharf development for Canary Wharf Group, this 58-storey tower stands approximately 210m tall at London, providing quality residential space with amenities such as a gym, pool and lobby on the lower three floors. The site is located within the old dock, so the tower is constrained only by the new Cofferdam that forms the boundary. The Wood Wharf masterplan extends to the north and east, where the tower extent will adjoin to the surrounding buildings. Since the site has been reclaimed from the dock, the enabling contract had many technical complications including building up the original dock bed level to the new basement profile.

Figure 3.1.b.1. One Park Drive tower

The substructure consists of 1.8 m-diameter piles, with a higher frequency of 1.5 m-diameter piles beneath the core, found in the Thanet sands at depth. The 2.5 m-deep raft extends beyond the retaining wall that forms part of the double-storey basement wall.

The structural concept adopted for the tower superstructure typically consists of reinforced concrete flat slabs supported by reinforced concrete blade walls and columns. The core of the tower is located centrally within the internal layout and is partially enhanced by frame action of the surrounding tower.

There are three main types of residential typologies: Loft, Cluster and Bay Window. These typologies offset and rotate around the building to form the tower's distinctive geometry, resulting in an evolving façade. A critical design consideration has been the tolerance and movement criteria that the floor slabs have been designed to meet, whilst maintaining the consistent shallow floor zone.

The project was developed by a team of 14, including Project Directors, Project Associate, Senior and Design engineers and Senior and Junior BIM technicians. The team was given 3 months to develop the concept design and to submit a Stage C report in August 2013.

Project Directors visited the site to communicate with the clients and to collect site information. The communication during the production was executed in a mixed mode including physical meetings; video conferences, telephone calls and messaging services were the main collaboration tools within the project team.

Incidents:

In the first stages of the project, a structural concept had to be found (Figure 3.1.b.1). This action is mainly a qualitative one, where the components and hierarchies of the structural scheme are sketched. Often several options can be thought of which relies on certain architectural conditions or uncertainties which will be explored with analysis further on. In this stage the project director and the senior engineers are interfacing with the client and the design team, understanding the brief, the constraints and the ambitions in terms of materiality and sustainability, and assessing the targets in terms of performance and cost. In this initial phase of the project the early CAD drawings, site material, investigations, photographic surveys, digital surveys etc are reviewed to understand both the existing conditions and the Architectural intent. In this instance, we have supported the Client and the architectural team in developing the first massing ideas.

In the first stages of the project, an initial site assessment has to be compiled looking at the history of the site, the existing documentation available in the local authorities databases and in the utility and services archives. This action is key to identify potential constraints related to the existing site (EG deep buried obstructions, services etc) that will affect the structural concept. After collating all the relevant information from the site, a site-specific constraints diagram is prepared. This document allows the team to coordinate with the rest of the design team, issues such as potential clashes with services, impact on proposed structural system, on massing and interferences.

The existing Geotechnical report has been received by the client, then this information is reviewed and used to extract the parameters needed for the design of the foundation system and the retaining structure, otherwise a site-specific assessment is requested upon issue of a brief for site investigations. The report includes a description of the various ground layers encountered, including detailed geotechnical aspects test results, interpretative reports.

On the base of the required use of the spaces and the architectural/client ambitions in terms of finishes/performance, a definition of loading is then prepared by the senior engineer and his team and documented using codified approach, material characteristics and performance requirements.

At this point a draft issue of a document highlighting the basis of design and the main parameters that we are selecting while developing the project (Design Life, loading conditions, reference codes, seismic and wind local parameters etc). To be approved by the client and design team.

Preparation of different structural modelling FEM (Finite Element Modeling), element design. Several 3D FEM models have been prepared by the senior engineer and his team to provide the wider team with fundamental considerations such as behaviour of the tower against lateral forces, impact of load takedown on foundation system, informing structural grids and typologies of structures. The work is done on instruction of the project design director and technical director that have defined the most appropriate structural typologies.

Evaluation and preparation of initial material estimates to be provided for a preliminary cost evaluation to be assessed by the relevant cost consultant, to be updated and included in the final report.

A series of sketches were prepared using Revit and Bluebeam to highlight the different structural options, layouts, findings, those will be then part of the conclusive report for this stage. The cad information is modelled to the appropriate RIBA level of detail. For the purpose of the report a general description of overall construction sequence has been prepared, highlighting the impact of alternative solutions on cost and time on site, also highlighting specific needs in terms of temporary requirements (eg propping and special permits road closures etc…) This has been done using Rhinoceros and Vray, to visually highlight the element in question. The senior engineer and his team prepared a Risk matrix Highlighting risks and opportunities identified in the current stage with relative levels of importance and mitigation measures

A report is redacted in the last weeks before the issue to compile all the relevant findings, describe the main structural findings, including all the relevant documentations from third parties collected during the phase, illustrating the risks and opportunities and collating all the sketches, drawings, and relevant correspondence for the project.

CASE STUDY 01 RESIDENTIAL PROJECT: STRUCTURAL DISCIPLINE INCIDENTS
One Park Drive / AKT II

CS1 AKT	PROJECT INFORMATION	MANAGEMENT	COMMUNICATION: HANDSKETCHES	COMMUNICATION:MARK-UPS	MASTER MODEL	3D SKETCH	STRUCTURAL ANALYSIS	SPATIAL ORGANISATION	DIAGRAMMATIC PLANS, SECTIONS & ELEVATIONS	INTERNAL DESGIN REVIEWS	EXTERNAL PRESENTATION	PHYSICAL & MOCKUP MODELS	SUBMISSIONS
2013			COLUMN LOADS AT THE BASEMENT B2 CORE LOADS AT THE BASEMENT B2				130123 Core model 130204 Full model updated floor plates 130219 1A-Loading Down Rev5				141014 Scheme Design Briefing Presentation		130820_A1 Stage C_final
2014			RAFT A1 EXTENSION COLUMN LOADS AT THE BASEMENT B2 CORE LOADS AT THE BASEMENT B2 RAFT A1 EXTENSION WIND X -DIRECTION: VERTICAL ELEMENTS IN TENSION AND COMPRESSION WIND Y -DIRECTION: VERTICAL ELEMENTS IN TENSION AND COMPRESSION REVIT MODELS COMPARISONS WIND 45 DEGREES DIR. VERTICAL ELEMENTS IN TENSION AND COMPRESSION WIND LOAD: RC WALLS C AND D BASEMENT: SAP MODEL JOINT NUMBERS FOR WALLS BASEMENT: SAP MODEL JOINT NUMBERS FOR WALLS (CORE) SIGN NOTATIONS FOR THE REACTIONS OF SAP2000 RESULTS CLUSTER: TENDONS ARRANGEMENT OPTION STUDY FOR THE CORE SLAB CLUSTER: TENDONS ARRANGEMENT OPTION STUDY FOR THE CORNER SLAB STRESSES WIND LOAD STRUCTURAL PROPERTIES WIND LOAD STRUCTURAL PROPERTIES MODAL ANALYSIS RESULTS		141031 - Full Model Issue		141128 PILE SETTING OUT A_1_FOUNDATION A_2_PILED RAFT ANALYSIS A_3_PILE HAND CALCULATION A_4_RETAINING WALL A_5_RAFT A_6_GROUND FLOOR A_7_WATERPROOFING STRUCTURE A_8_CONSTRUCTION SEQUENCE A_9_MODELS A_10_COLUMN DESIGN B_11_STAGED CONSTRUCTION ANALYSIS B_12_ACCELERATION B_14_EVALUATION OF SPRINGS EFFECTS B_9_PC STAIR		141112-Core Slip Form Options 141219 Info issue				140904_Amenities Update
2015			PILE SETTING OUT GROUP LEVELS AND ELEMENTS DEFINITIONS AMENITY SLAB CONCRETE OPTION AMENITY SLAB STEEL OPTION CLUSTER SLAB OPTION WET SCREED AGAINST DRY SCREED VERTICAL ELEMENTS DESIGN NOMENCLATURE INTERFACE A1 B2 INFRASTRUCTURE B2 INTERFACE A1 FOUNDATION WITH BANANA WALL BASEMENT TO 2ND FLOOR MARK UP INTERFACE A1_INFRASTRUCTURE BASEMENTS COLUMN SIZE TO BE MAINTAINED UNTIL ROOF LEVEL				150625_RC Estimates 4.12 Panoramic levels		150213 -Stage DD1 150401 Piling T2 150621- TENDER ADDENDUM ISSUE (CONSTRUCTION SEQUENCE) 151015 - B2 SLAB For Comment				150327_A1 Stage D 150805- FOR CONSTRUCTION 151208_Construction Issue
2016			CRANE BASE CORE VE OPTION STUDY PILE LAYOUT UPDATED WITH INFRASTRUCTURE PILES PROPOSED RETAINING WALL AND MAIN RAFT LAYOUT PILE REACTIONS COMPARISONS				180723 Reduced Portal Frame 180817 Roof Louvre 4_1_Building Control 4_2_Floorplates 4_5_Foundation 4_7_Marine Deck 4_8_VERTICAL ELEMENTS 4_9_Optimisation 4_10_Stairs 4_12_Staged Construction Analysis 4_16_BASEMENT WALL		160127 - Issue RFI amendment 160206 - DRAFT Issue - Walls & Columns LB2-L00 160318 - Core Draft Issue 160323 - Monitoring Points 160415 - C_penthouse elevs				160212 - CONSTRUCTION ISSUE - Walls & Columns LB2-L00 160304 - CONSTRUCTION ISSUE- GF 160629 - C_RC INTENT - Core walls L55 to Roof
2017			PILE HEAD AXIAL FORCE COMPARISON LOCATIONS OF OPENINGS IN RETAINING WALL LOCATIONS OF OPENINGS IN RETAINING WALL SECTION CUTS AND DISCONTINUITY REGIONS EXPOSED CONCRETE LOCATIONS AMENITIES SLAB - BEAM PENETRATIONS RETAINING WALL VENTILATION/MARINA DECKING		171116 - 3D Model		5.10 Panoramic levels 5_2_Floorplates		170725 - Core Risers 170823 - Fire Escape Stairs				170406-Building control reports 170320 ISSUED FOR CONSTRUCTION
2018			ALLOWABLE BW HOLES: L02 CRANE POSITION COLUMNS FROM B02 TO UNDERNEATH GROUND FLOOR		180417 - Revit Model		5_3_RC Intent 5_4_Vertical Elements 5_5_FEM 5_6_RFI Design checks 5_7_NCR Design checks 5_8_Stairs 5_9_RC Est 5_10_Marine decking 5_11 Axial Shortening Monitored Results Graph		180208 - Bay Window Slabs Punching Shear 181004 - Panoramic Redesign				
2019													

Figure 3.1.b.1: Incidents for the the One Park Drive

Higher resolution / excel sheet

3.1.c CASE STUDY 2b: MEP: One Park Drive / Sweco

Project Description:

One Park Drive is a project under construction in Canary Wharf, London. Designed by Herzog & De Meuron Architects as part of Canary Wharf groups, Wood Wharf development. Also known as Wood Wharf Building A1, the flagship building of the development comprises 483 apartments within a 58 storey residential tower with retail and amenities on the ground floor and level 1. The building has three distinct zones known as loft, cluster and bay window offering different types of accommodation, that is clearly expressed, offering a sense of individuality in a larger development.

Sweco was appointed directly by the client for this project. The project was developed by a team of 21 professionals, including Project Director, Project Manager, MEP Leads (Mechanical, Electrical, Public Health), Design engineers (Mechanical, Electrical, Public Health, Sustainability), BIM & ITAC Specialists and technicians.

The main communication method with the client and architect consists of emails and regular meetings. Internally SWECO utilises Bluebeam Revu and BIM360 for mark-ups. Externally, the mark-ups of drawings are communicated via online platforms i.e. Asite in accordance with document control protocols set and managed by the client.

Client/Architect presentations and design workshops/meetings are organized as required to assess options suitable for the project. Several presentations are also deliberated internally to design teams and externally to architect/client after the completion of each stage to inform of services designed, in addition to MEP services presentations to Building Controls for approvals.

Technical Innovation

One Park Drive was one of the first high rise towers within the UK and by SWECO to be designed using the Autodesk Revit software package. Revit allows all consultants to collaborate and provide a highly coordinated building, structure and services in 3D. Revit allows the process of continuous improvement for end-users to quickly identify clashes before they reach the site, minimising costly delays associated with poor coordination.

Project Timetable and incidents

Sweco was provided with a draft residential brief from the client to which Sweco developed a stage 2 package over a few months from February through to June 2012. The first design change was introduced in July 2015; the client decided to switch the interior designers for the apartments and appointed three new interior designers for the three topologies of the building. The client tried to shield the interior designers from each other to avoid influencing one another. Sweco was tasked to coordinate with the interior designers and developed comprehensive production information over months spanning from June 2015 to April 2016. The client decided to go down the route of IDNO for electrical design. ESM Power – DNO designers, were appointed by the client. Sweco liaised with ESM to design the electrical infrastructure and associated plant rooms. Stage 3 package was issued April 2016.

By June 2016, the project moved from schematic design to detailed design which involved designing shell and core, fit-out and pod packages. The pod package was particularly challenging as the building was changing its shape for all three topologies, which also made aligning the verticality and minimising the offsets of the soil vent stacks difficult. Electrically Sweco came up with an innovative pod design complying with the BS requirements which was then adopted across multiple residential buildings within the development. Amenity areas of the building went through a major revamp to include a leisure facility comprising reception, treatment rooms, office, staff rooms, swimming pool, changing rooms, fitness studio, sauna and steam room. Sweco were tasked to coordinate with RCH (Gym and Swimming pool consultants) to come up with a coordinated tender pack. Sweco developed the tender design over a few months from April 2016 through to July 2017. The final tender issue involving shell and core, fit-out and amenity design was issued for tender in late 2017. A further significant change was instructed in 2019 when the client decided to change the penthouse apartments to duplex apartments spanning across two floors each with roof gardens. The client believed that introducing a roof garden would be a unique selling point amongst the overcrowded London residential market. The final construction pack for the design of the panoramic apartment along with shell and core changes were issued in late 2019.

Technical Challenges:

By design One Park Drive provides a number of engineering design challenges. Due to the height of the building, it was necessary to provide two hydraulically independent circulating systems serving low and high zones for both LTHW and CHW within the building in order to limit the pressure rating to PN16 at the residential interfaces. The building comprises three distinct topologies known as Loft, Cluster and Bay Window apartments whereby the floorplates vary significantly. This provides complexities for vertical services distribution where the core needs to be carefully configured to minimise unnecessary offset services and the loss of value associated.

Given the building's slenderness ratio, the available plant room space within the basement was moderate compared to buildings with larger floorplates. This creates numerous coordination difficulties and with space at a premium careful and accurate multi-discipline coordination from an early design stage was essential.

The introduction of panoramic apartments meant that risers at level 56 and 57 were wiped out. SWECO investigated possible alternative routes for the MEP services and suggested a workable solution to the client. The fit out design has no ceiling void, SWECO suggested that the client route all the electrical services in conduit within the concrete slab, which involved a lot of coordination with structural and architectural designers.

In the following a list of incidents is presented about the MEP design of One Park Drive. Afterwards, a sequence of BIM designs is listed. Since it is sensitive information, the figures are blurred on purpose. If the readers want higher resolution images, they can address project authorities.

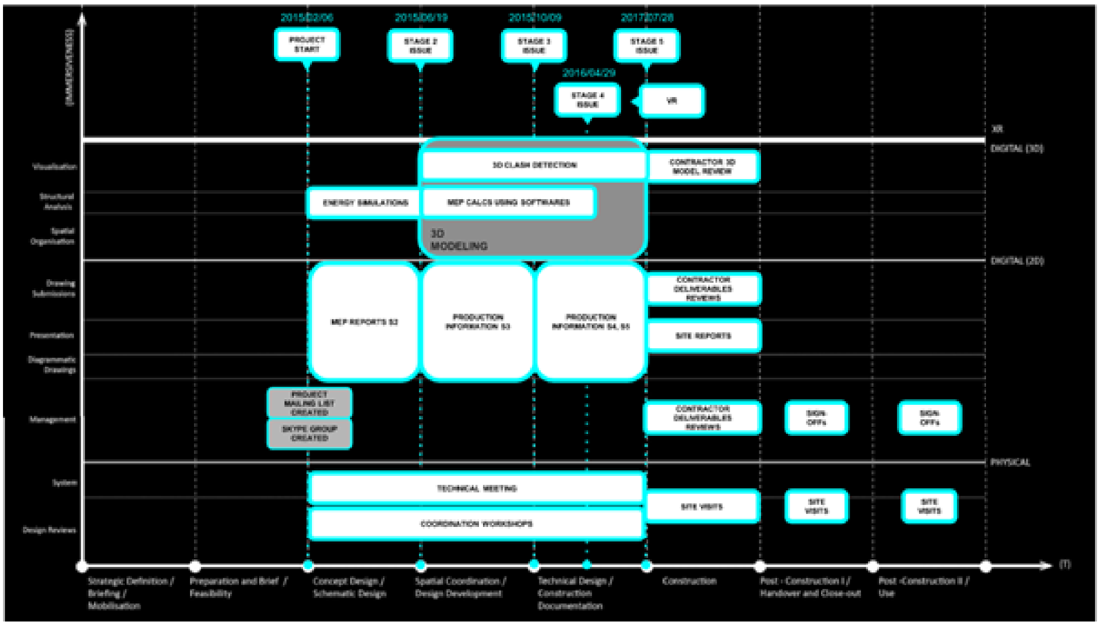


Figure 3.1.c.1 - The timeline of the MEP design development

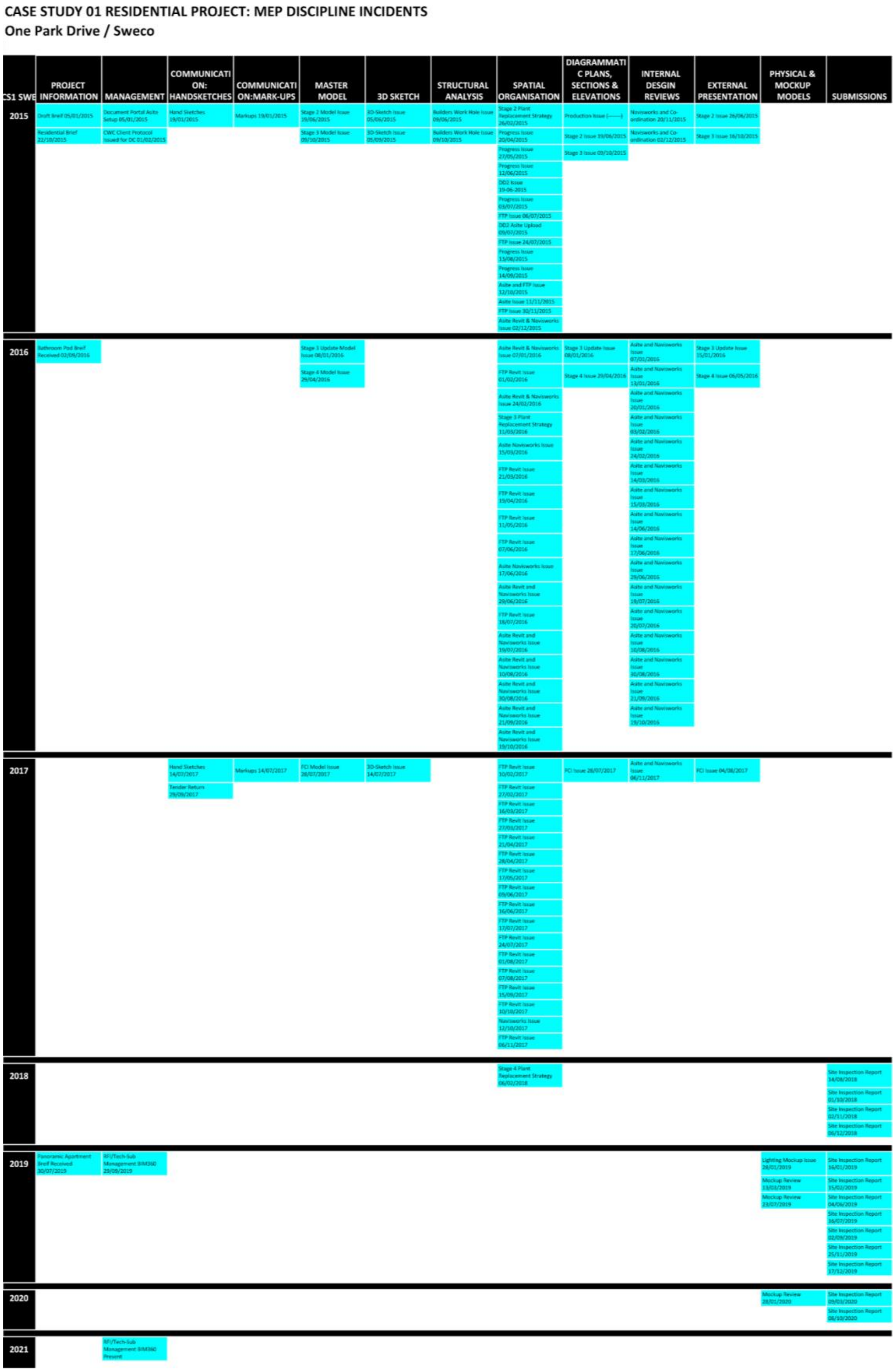


Figure 3.1.c.2: Incidents during One Park Drive with respect to MEP design. Higher resolution / excel sheet

Figure 3.1.c.3 - Sample building external analysis

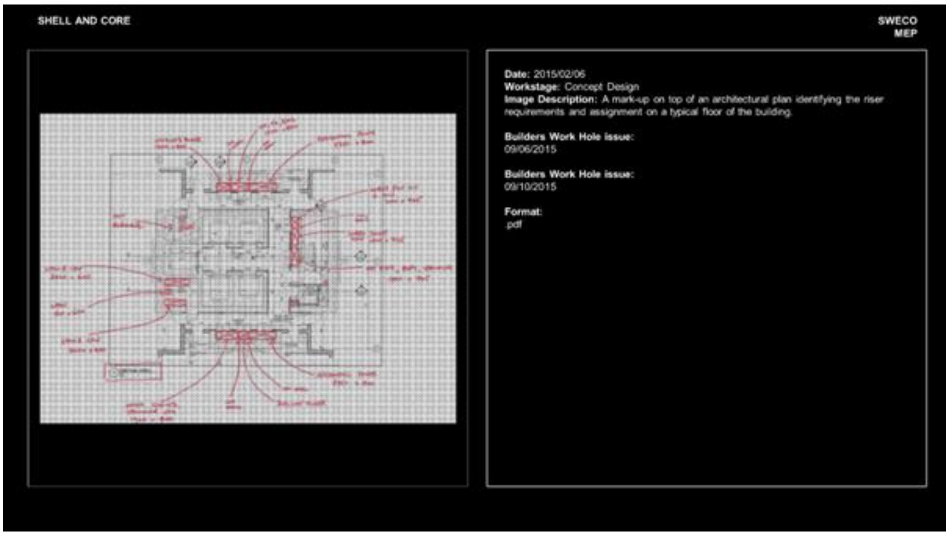


Figure 3.1.c.4 - Sample riser mark-up

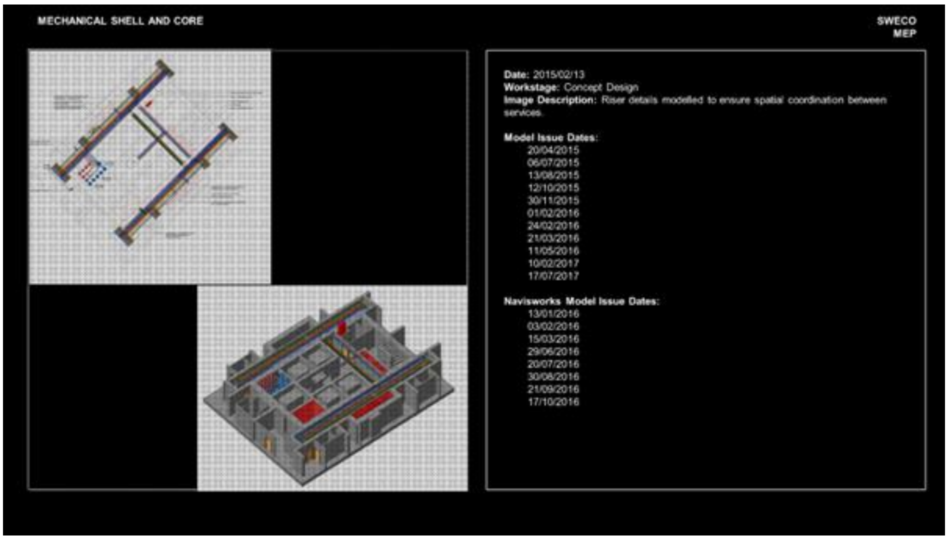


Figure 3.1.c.5 3D model of the core for coordination

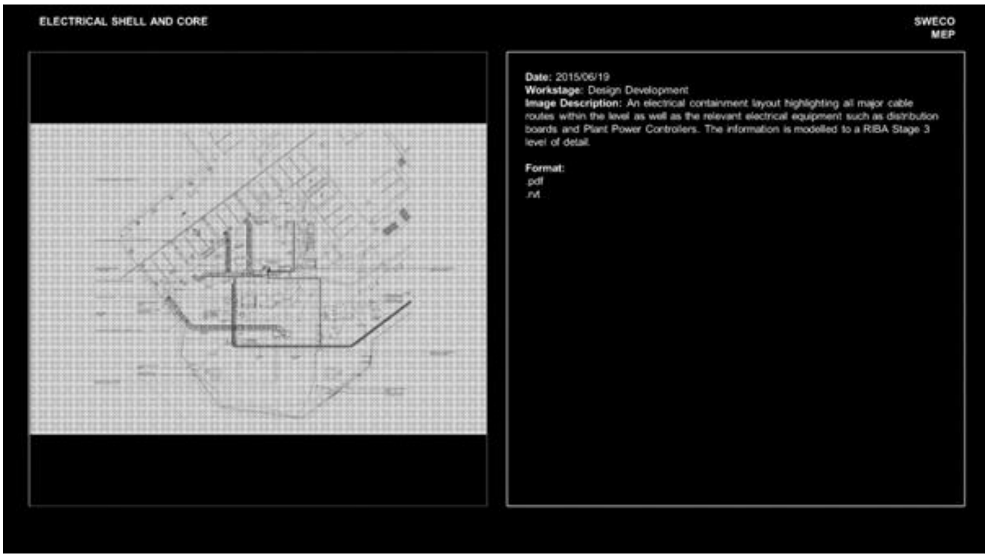


Figure 3.1.c.6 - Typical stage 3 Shell and Core Electrical Layout

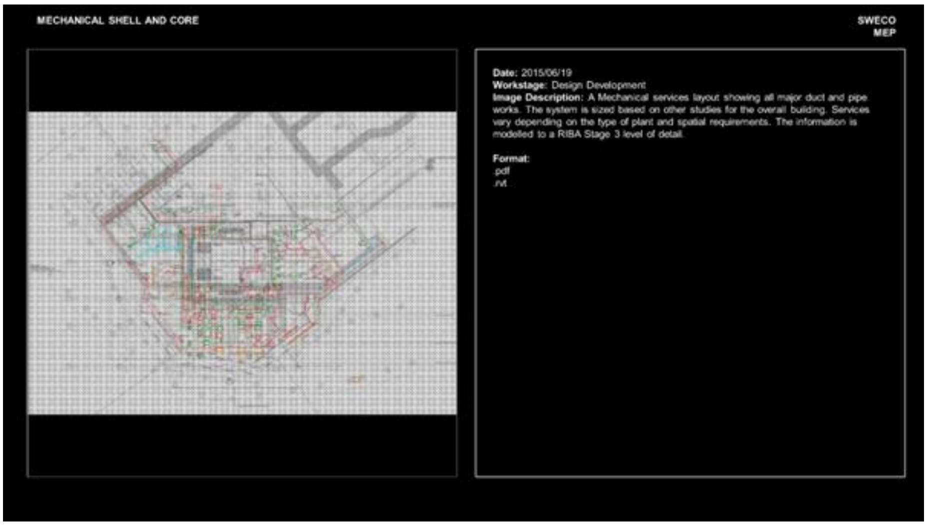


Figure 3.1.c.7 - Typical stage 3 Shell and Core Mechanical Layout

Figure 3.1.c.8 - Typical stage 3 Shell and Core Public Health Layout

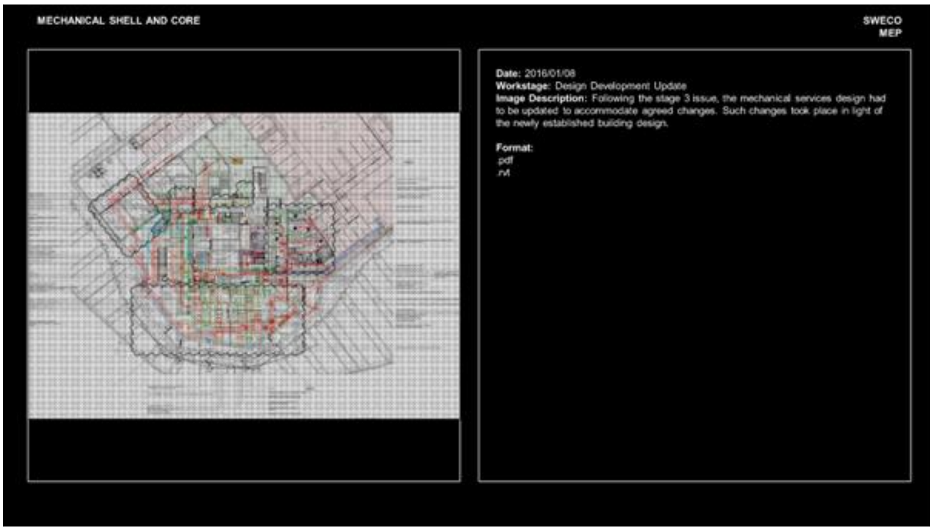


Figure 3.1.c.9 - A mechanical layout showcasing the design update

Figure 3.1.c.10 - Typical stage 4 Shell and Core Electrical Layout

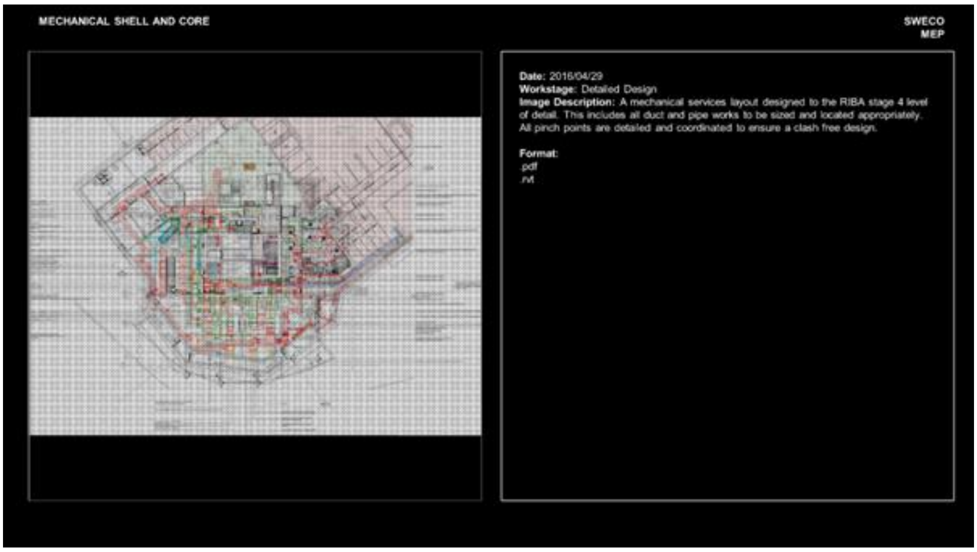


Figure 3.1.c.11 - Typical stage 4 Shell and Core Mechanical Layout

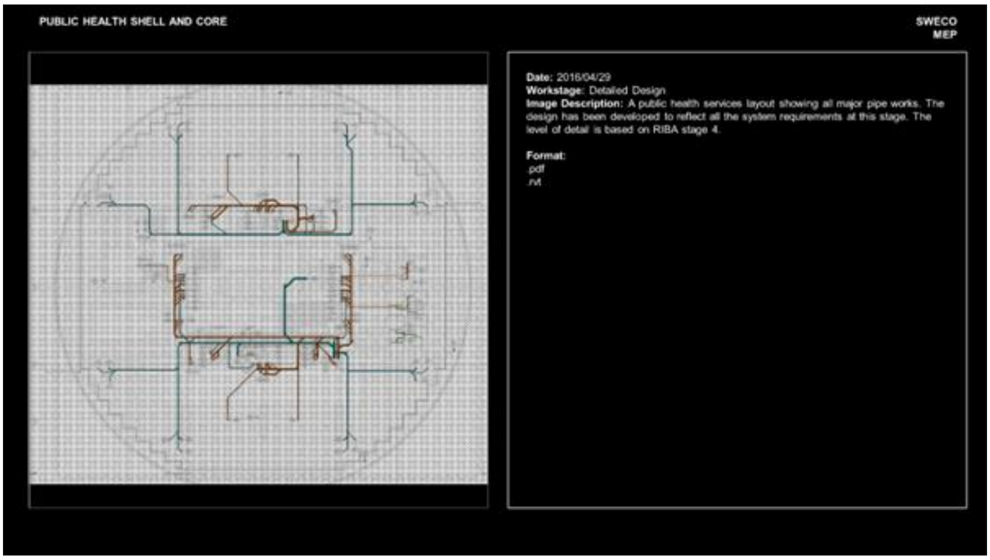


Figure 3.1.c.12 - Typical stage 4 Shell and Core Public Health Layout

Figure 3.1.c.13 - A physical coordination meeting to solve design issues

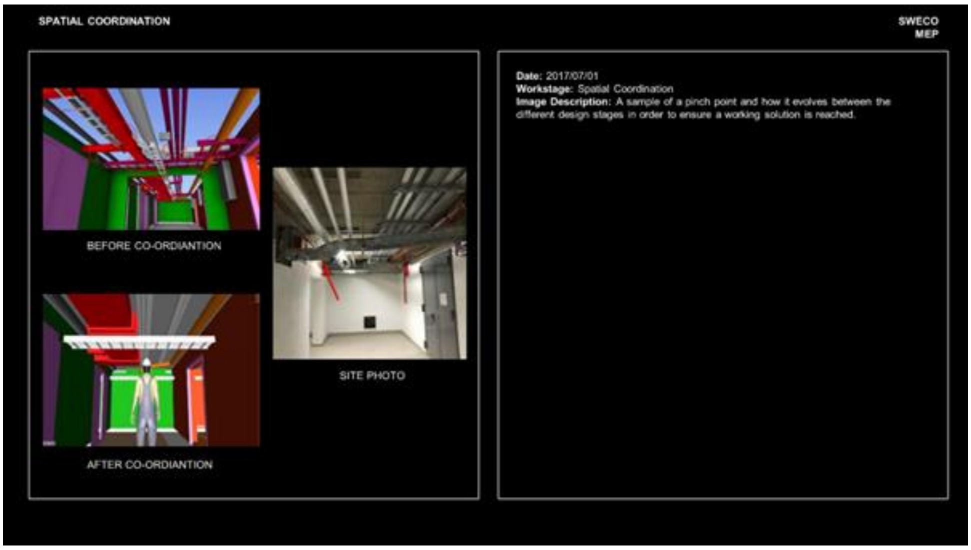


Figure 3.1.c.14 - The utilisation of software to solve clashes

3.2.a CASE STUDY 3: Architecture: One Thousand Museum / Zaha Hadid Architects

The One Thousand Museum tower is a project recently completed by Zaha Hadid Architects for a commercial developer client in Miami, Florida, United States. Applying design and construction techniques developed successfully on ZHA's projects around the world—including permanent glass fibre reinforced concrete (GFRC) formwork that requires minimal finishing and maintenance—One Thousand Museum's 62-storey concrete external structure offers areas uninterrupted by internal columns and represents a line of research in high-rise construction that merges fluid architectural expression with advanced engineering (Figure 3.2.a.1).

Figure 3.2.a.1: One Thousand Museum building. Project photography copyright Alena Graff 2019

The architectural team consisted of 26 people, including the roles of Project Director, Project Associate, Project Architect, Project Contributors from both architectural and interior departments. Structural engineering firm Desimone and the engineering firm HNGS were in direct contractual agreement with O'Donnell Dannwolf Partners Architects (ODP) from the onset of the project. All other consultants were hired directly by the owner. The client appointed the list of authors below individually:

- Design Architect
- Local Architect
- Structural Engineer
- MEP Engineer
- Civil Engineer
- Landscape Designer
- Facade Waterproofing Consultant
- Fire Protection Engineer
- Lighting Consultants
- Main Contractors
- Facade Contractor
- Glazing Contractor
- MEP Contractor

Design options were explored at different resolutions with consultations from engineers and providers from 2012 to 2016 throughout the concept stage towards the construction stage (Figure 3.2.a.2). The local building regulations changed during the construction executed instage and designers had to access the submitted 3D models again to amend the latest slab design. The 3D sketching exercise at the early stage of the project development was completed in two parts - Tower and Podium - from November 2012 until January 2013.

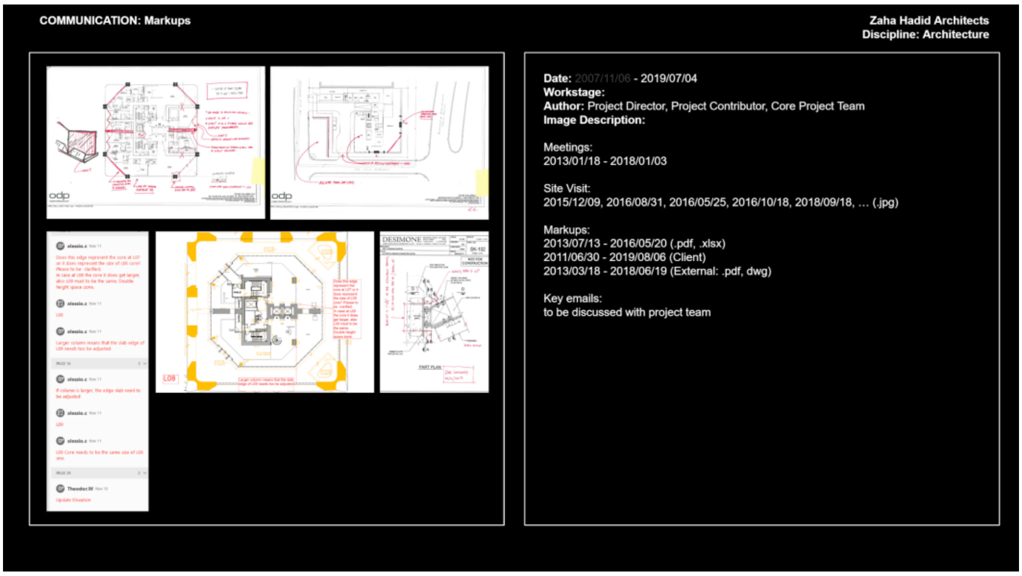


Figure 3.2.a.2 Mark-ups in consultation with clients and disciplinary partners

Maya software was used for early 3D sketches, and Rhino 3D software was used to refine the massing of the tower, and was also used for the interior design (Figure3.2.a.3). The geometry developed via 3D computer modelling using Rhino was then precisely documented (translated into 2D drawings) using Microstation and plotted point by point for accurate set-out, fabrication, and co-ordination in the field (Figure 3.2.a.4). However, not all of the drawings made for the drawing submissions were actually used at a later stage. Screenshots and renders of the master 3D model and cutaway views taken from different angles and overlaid with leaders, text, and other 2D information were helpful to visually communicate and also to explain each part's connectivity to the whole. Rationalisation studies were carried out by the architects in Rhino 3D software to find opportunities to simplify the geometry and find efficiencies for construction.

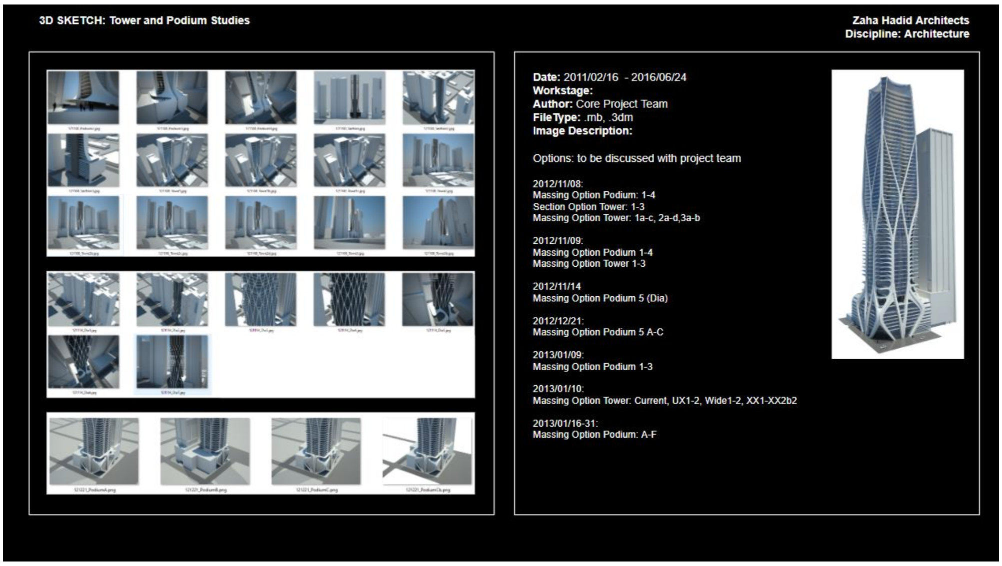


Figure 3.2.a.3 Tower and Podium studies using Maya and Rhino 3D Software

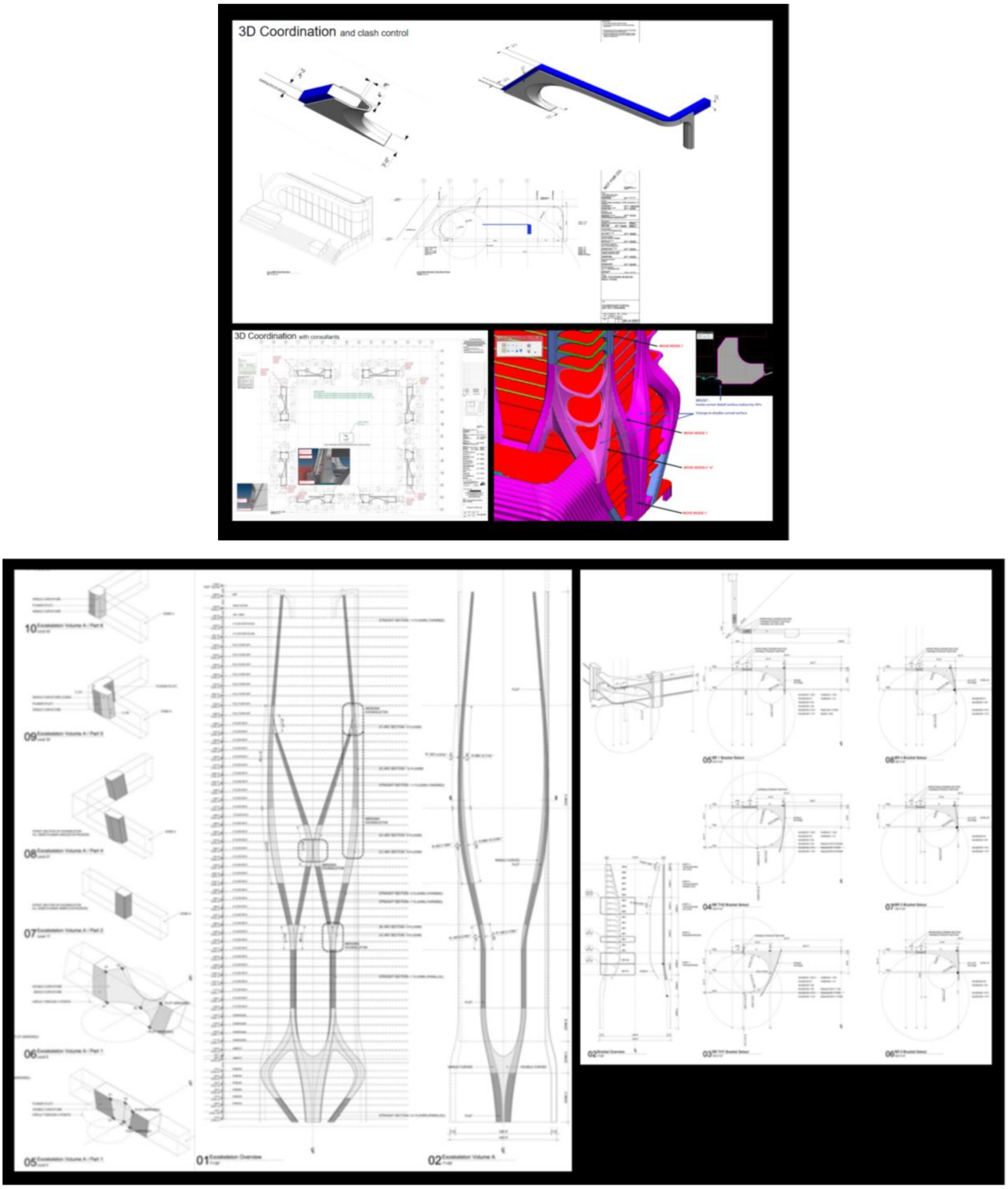


Figure 3.2.a.4 Documentation of the tower design using Microstation

Presentations were organised regularly. Open internal presentations were organised to share the project progress within the colleagues and external presentations were organised with external disciplines to develop the project. Client presentations were arranged to request feedback from the clients and selected options were presented by each discipline. The project team also gave a presentation on the completed project in public as an office representative project for marketing purposes (Figure 3.2.a.5). The project team handed over selected images to the archive team and the press team promoted the selected images to expose the project completion to the public. For some web publications, the project team submitted project options to show the project development.

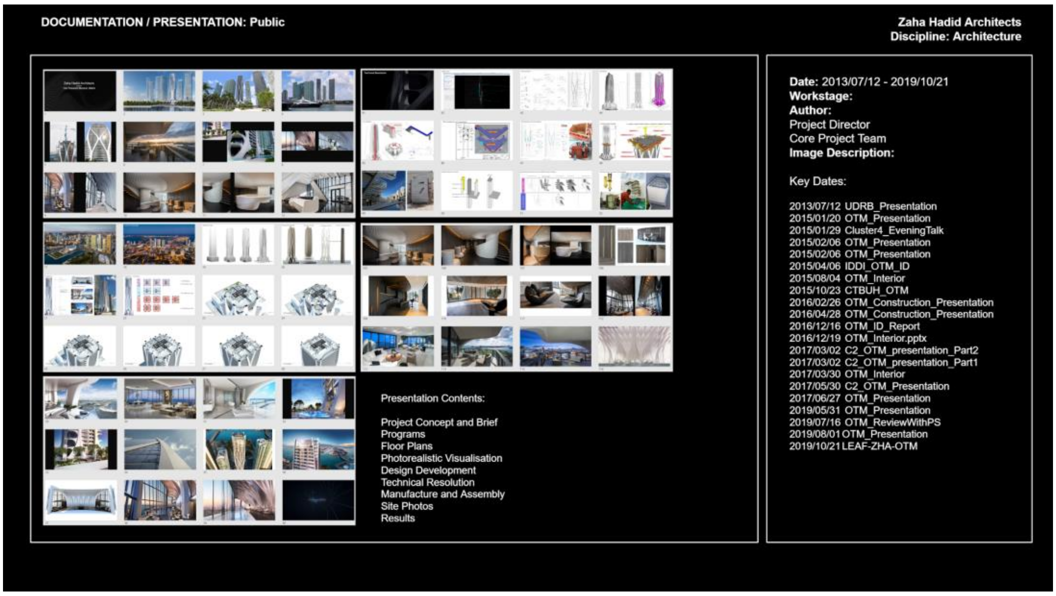


Figure 3.2.a.5 Sample presentation content

Technical Challenges

Miami experiences seasonal hurricanes, so the building was designed to withstand winds of up to 180mph. Constructing the 216m tall concrete exoskeleton to precision, at height, and to a demanding construction program was also a challenge that required collaboration, testing, and an innovative technical solution (Figure 3.2.a.6).

- The construction systems used on the building are listed below:
- Expressed Concrete Structural Exoskeleton using GRFC permanent formwork
- Reinforced Concrete Core and Shear Walls
- Post Tensioned Concrete Slabs
- Miami Dade Hurricane approved glazing systems.
- Bespoke GRP Louvres and metal rails to parking garage
- Perforated GRP cladding panels to Podium

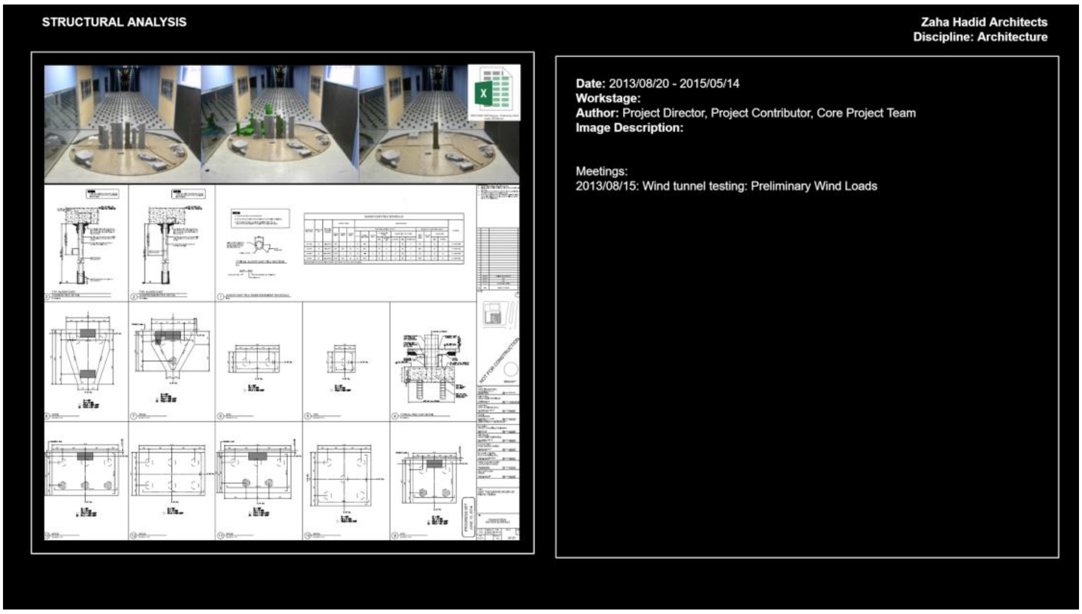


Figure 3.2.a.6 Structural analysis: wind tunnel testing

Technical Innovation

A world first construction system was developed using Glass Fibre Reinforced Concrete (GFRC) permanent formwork. Factory-made GFRC panels, which provide the formwork and the architectural finish, are assembled, level by level, around steel reinforcement cages, then filled with high strength concrete. CNC cut moulds were built in Dubai using information generated directly from the architectural model. GFRC panels were formed in the moulds, with a specified architectural finish to the face mix. Following factory test assemblies and mock-ups, the panels were shipped to Miami for use as the formwork (Figure 3.2.a.7).

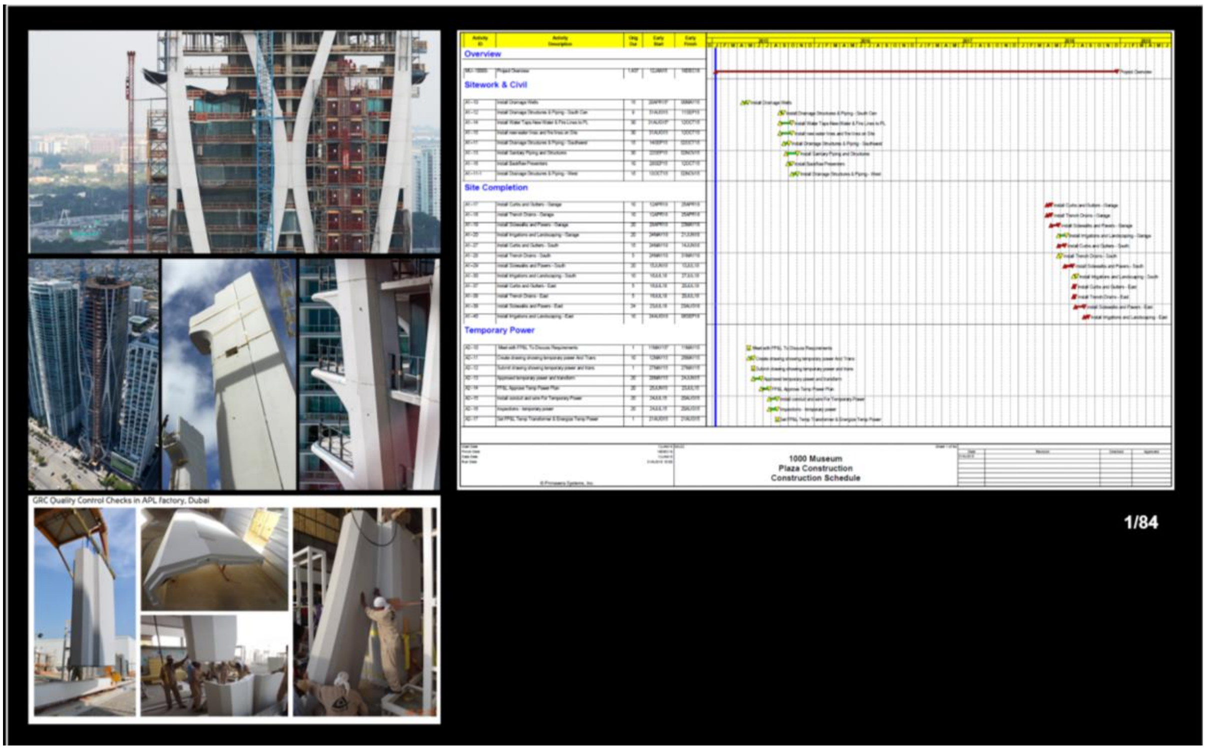


Figure 3.2.a.7 Site photos and construction sequence using precast GFRC panels

Project Timetable & Incidents

Contrary to the traditional linear narrative that is provided after the project's completion, the case study research clearly shows that the process of developing a complex architectural design is dotted with revisions, design changes, and other unforeseeable events that influence the development and outcome of the project. The project began in late 2012 as a direct commission from the client. Zaha Hadid Architects partnered up with local firm ODP to provide design services for the tower. ZHA developed the concept over a few months in December 2012 through March 2013. The first design change was introduced by the client in early 2013, at the end of the concept stage. In consultation with their estate agents, the owners decided that they wanted a maximum of two units per floorplate, whereas in the early concept, one third of all the floorplates contained three (Figure 3.2.a.8).

By April 2013, the project moved into Schematic Design, and in July, the planning documents for the tower were submitted. It was then that the owner asked for a redesign of the podium facade, which took three months, overlapping with the Design Development phase of the project. Another significant change stemmed from insurance requirements due to new regulations, requiring the ground floor level to be moved to +10. A plinth had to be designed to negotiate between the existing grade and the ground floor. The changes introduced numerous adjustments to the entire tower. As a result of moving the ground floor and requiring more height on level 8 and level 9, 1" or 2" was removed from a series of levels and redistributed to the podium levels. This involved Adjusting the glazing line setting out on every level, remodelling portions of the exoskeleton, and adjusting all sections.

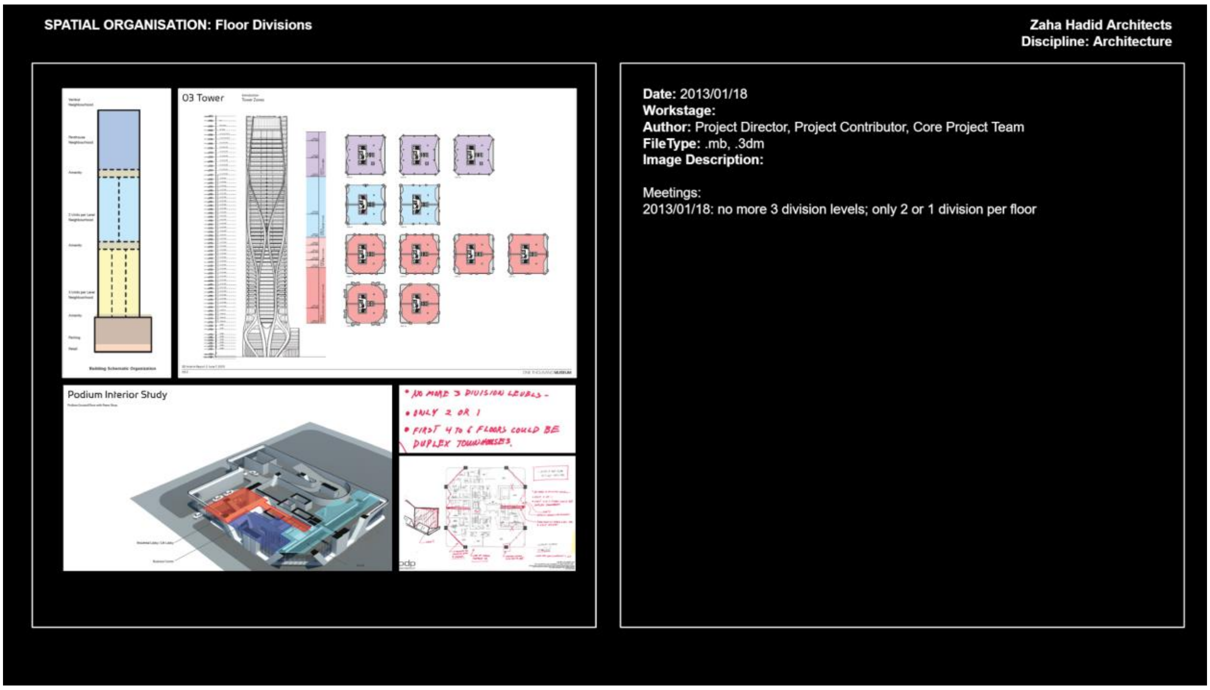


Figure 3.2.a.8 Documentation of floor divisions

The planning application was approved in October 2013. Next, the Tender Documentation (TD) was developed from March to August 2014. Structural changes were introduced in July. ZHA had initially suggested pre-cast GRFC formwork for the structure of the building, having investigated this system for a prior project, highlighting its time-saving and quality-control benefits on site. However, because this system had not been deployed previously in the USA, it provided a legal risk to the owner.

Having worked to optimise the geometry for a more commonplace cast-in-situ concrete formwork solution, there was a change of directive: one of the main financial backers made a strong case for accepting the risk, and it was decided to proceed with the innovative GFRC precast formwork for the building (Figure 3.2.a.9).

When asked how the ZHA team worked with such a high level of uncertainty, the Project Director replied, ”You keep working at risk. You know where the variables and the uncertainties are at any given moment. You keep focusing on the parts where you could salvage most of the work, even if the system changes.” The project underwent a stringent optimization process by the engineer under the name DIP4, and the guaranteed Maximum Price Tender was agreed in early 2015. Works on site began in the summer of 2015 and lasted until completion in 2019.

The interiors were a separate appointment, consisting of the main entrance lobby, gym, the spa at levels 8 and 9, and the top of tower amenity (Figure 3.2.a.10). ZHA was brought in March 2015 and had three months to submit an interior report. This additional scope allowed ZHA to carry out the interiors for their own building, continuing the building’s design language indoors. For example, on the ground level, the residential lobby and drive court is unified by a rippling feature wall and ceiling, with a unique reflective pattern embedded in the panels that shimmers in the light. Higher up, at the pool deck and spa on levels 8 and 9, a feature “tornado” stair connects the two levels of the spa facility with one sweeping gesture. These incidents that took place during the project are provided in Figure 3.2.a.11.

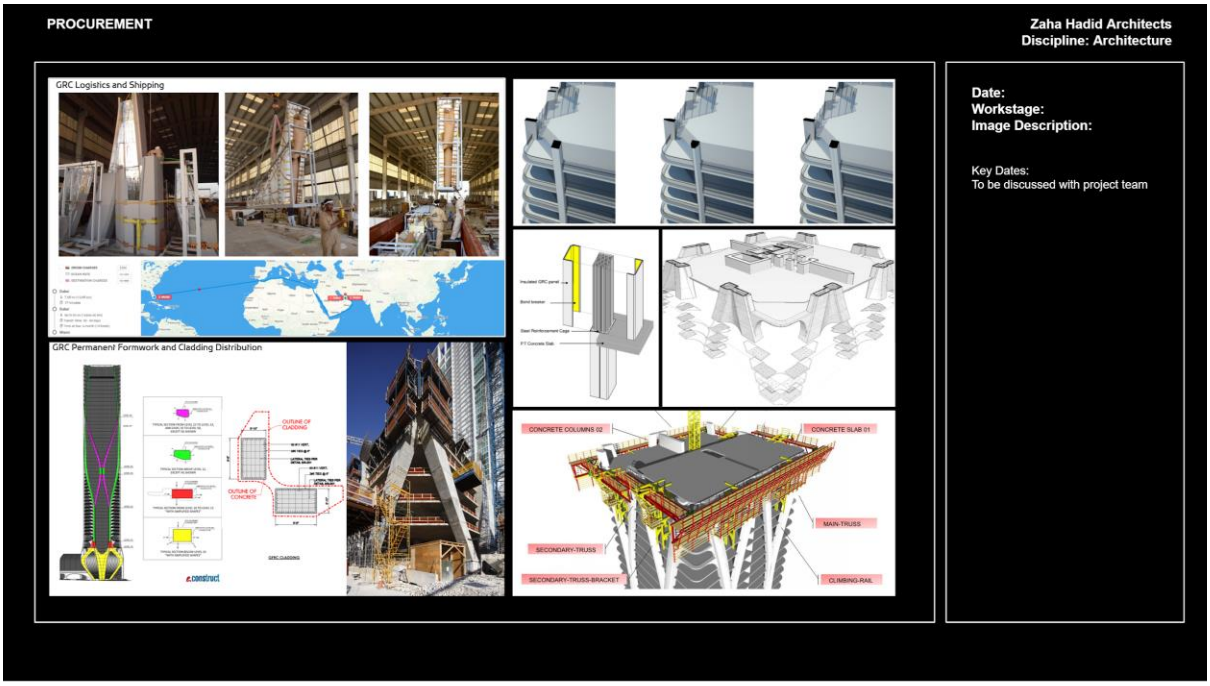


Figure 3.2.a.9 Producement: studies for traditional cast-in-situ formwork

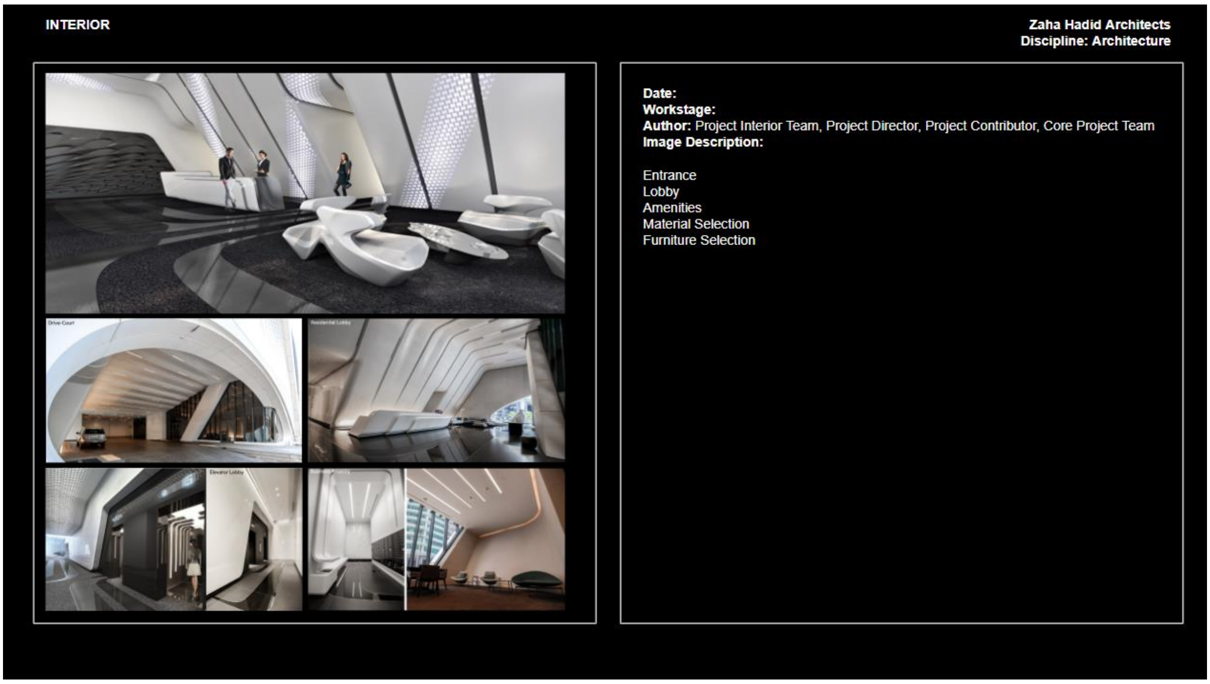


Figure 3.2.a.10 Interior design for public areas and amenity zones of One Thousand Museum

CASE STUDY 02 COMMERCIAL PROJECT: ARCHITECTURAL DISCIPLINE INCIDENTS
One Thousand Museum / Zaha Hadid Architects

CS2 ZHA	PROJECT INFORMATION	MANAGEMENT	COMMUNICATION: HANDSKETCHES	COMMUNICATION:MARK-UPS	MASTER MODEL	3D SKETCH	STRUCTURAL ANALYSIS	SPATIAL ORGANISATION	DIAGRAMMATIC PLANS, SECTIONS & ELEVATIONS	INTERNAL DESGIN REVIEWS	EXTERNAL PRESENTATION	PHYSICAL & MOCKUP MODELS	SUBMISSIONS
2011				MarkupsClient: 2011/06/30									
2012	Brief: 2012/10/19 Local Regulations: 2012/10/25		PatrikComment: 2012/11/01 InternalReview: 2012/11/05		Massing Option Tower: 2012/12/21	Massing Structure: 2012/12/13			Architectural Elevations: 2012/11/14				
2013		Monthly Report: 2013/03/04		MarkupsExternal: 2013/03/18 Markups Internal: 2013/07/13	Massing Option Podium: 2013/01/16-31 Massing Option Podium: 2013/05/16		Structural testing: 2013/08/15	Sturctural Organisation meeting: 2013/01/18 Circulation Concept: 2013/03/01		InternalReview_z: 2013/01/31 InternalReview_z: 2013/02/01 InternalReview_z: 2013/02/25 InternalReview_p: 2013/03/18 InternalReview_p: 2013/04/26 InternalReview_z: 2013/05/17 InternalReview_p: 2013/06/07 InternalReview_z: 2013/06/10 InternalReview_p: 2013/07/10 InternalReview_z: 2013/09/06	OTM_ID_Report: 2013/07/12		PLANNING SUBMISSION July 2013 PLANNING APPROVED Oct2013
2014	Budget: 2014/04/28					Structure changes: 2014/07/23			Area Study: 2014/05/22	InternalReview_p: 2014/10/10		ModelMaking: 2014/11/26	
2015	Site Info: 2015/03/09	Monthly Report: 2015/09/01	Site Visit: 2015/12/09		3DModel_TWR_FAC: 2015/06/02 3DModel_TWR_BAL: 2015/06/23					InternalReview_z: 2015/06/10 InternalReview_z: 2015/06/16 InternalReview_p: 2015/07/14 InternalReview_z: 2015/07/20 InternalReview_z: 2015/08/11	OTM_Presentation: 2015/01/20 Cluster4_EveningTalk: 2015/01/29 OTM_Presentation: 2015/02/06 IDDI_OTM_ID: 2015/04/06 CTBUH_OTM: 2015/10/23	ModelMaking: 2015/05/14	SITE MOBILISATION June 2015
2016	Buduget: 2016/02/17 Brief: 2016/06/17		Site Visit: 2016/05/25 Site Visit: 2016/08/31 Site Visit: 2016/10/18	Markups Internal: 2016/05/20	3DModel_TWR_Corner_BAL: 2016/01/27	Massing Structure: 2016/02/24					OTM_Construction_Presentation: 2016/02/26 OTM_Construction_Presentation: 2016/04/28		
2017	Contact: 2017/03/28	Action List: 2017/02/16			3DModel_POD_FAC_AMD: 2017/03/09 3DModel_TWR_SLB: 2017/04/11 3DModel_TOB_SLB: 2017/05/15 3DModel_TOB_CEILING: 2017/11/03 3DModel_POD_FAC_LVR: 2017/12/14 3DModel_EXO: 2017/12/21						C2_OTM_presentation: 2017/03/02 OTM_Interior: 2017/03/30 C2_OTM_Presentation: 2017/05/30 OTM_Presentation: 2017/06/27		
2018			Site Visit: 2018/09/18	MarkupsExternal: 2018/06/19	3DModel_POD_SLAB: 2018/01/15 3DModel_POD_CABANA: 2018/07/02 3DModel_POD_INT_CEILING_pattern: 2018/07/04 3DModel_SITE: 2018/07/13 3DModel_TOB_FAC: 2018/11/13								
2019	Site Info: 2019/07/03			Markups Client: 2019/08/06	3DModel_POD_FAC_CLD_Storefront: 2019/01/03 3DModel_POD_LND_001: 2019/02/01 3DModel_POD_LND_008: 2019/05/09 OTM_POD_FAC_CLD: 2019/05/13					InternalReview_p: 2019/07/16	OTM_Presentation: 2019/05/31 OTM_ReviewWithPS: 2019/07/16 OTM_Presentation: 2019/08/01 LEAF-ZHA-OTM: 2019/10/21		COMPLETION July 2019
2020	Admin: 2020/12/21	Action List: 2020/10/25 Schedules: 2020/10/25											

High resolution / excel sheet

Figure 3.2.a.11 Incident Sheet

3.2.b CASE STUDY 4a: Structure: Bankside Yards West - Building 3 / AKT II

This residential-led masterplan in central London will create nine new buildings of housing, office, cultural, retail and leisure space, all positioned around a landscaped public realm. Following our work on the neighbouring 240 Blackfriars and South Bank Tower, we are working with PLP Architecture and Make Architects on two residential towers and an office block. Adamson Associate Architects has been appointed as the delivery architect for the west basement and Building 2. The site is currently home to Sampson House and Ludgate House. The former is a 9-storey block for Lloyds Bank and the latter is an 11-storey headquarters. These will be demolished as part of the redevelopment, and thus existing basements and retaining walls have been considered in the design. There are also other ground constraints to consider including Network Rail assets and the close proximity to Blackfriars station, with the railway lines running through the site. This brings a host of design and construction complexities that require a holistic approach to the whole masterplan for the area. Also of consideration is the close proximity to the River Thames; in particular, the existing river wall needs to be understood early in the design process. The two towers, the tallest reaching to 53 storeys, will be predominantly residential, with the option of retail on ground floor. They will be square extrusions, with column grids and floor-to-ceiling heights that respond to the needs of the residential units. Prefabrication and the logistical considerations on such a constrained site will be key to unlocking the project's full potential, as will investigations into the integration of the structure with the façade approach.

Building 3 which is the focus of this test case scenario is a 20 storey office building. The building orientation is parallel to the viaduct. To the east the building over-sails the NWR viaduct used as a lay-by area. The South and West elevations of the building are facing Southwark Street and Blackfriars Road respectively. The north elevation is facing the Building 2 tower. The massing of the building reduces between ground floor and level 3 to create a public realm accessed from Blackfriars Road and Southwark Street at the location of the current Invicta Plaza.The building has a trapezoidal shape on plan with overall dimensions of 68.5mx28.3mx49.0mx34.3m and a maximum height above ground of circa 84 m for the lifts overrun. The superstructure is formed by a steel frame system comprising steel columns and beams, with composite slabs.

The building can be divided in three main parts:

- Podium levels, which include the ground mezzanine floor, and Level 1 to 3.
- Open office floors from Level 4 to 18.
- Roof levels, which include Level 18M to the roof.

Incidents

In the first stages of the project, a structural concept had to be found. This action is mainly a qualitative one, where the components and hierarchies of the structural scheme are sketched. Often several options can be thought of which relies on certain architectural conditions or uncertainties which will be explored with analysis further on. In this stage the project director and the senior engineers are interfacing with the client and the design team, understanding the brief, the constraints and the ambitions in terms of materiality and sustainability, and assessing the targets in terms of performance and cost. In this initial phase of the project the early CAD drawings, site material, investigations, photographic surveys, digital surveys etc are reviewed to understand both the existing conditions and the Architectural intent. In this instance, we have supported the Client and the architectural team in developing the first massing ideas.

In the first stage of the project, an initial site assessment has to be compiled looking at the history of the site, the existing documentation available in the local authorities databases and in the utility and services archives. This action is key to identify potential constraints related to the existing site (EG deep buried obstructions, services etc) that will affect the structural concept. The history of the site and its surrounding area has been assessed using extracts from John Rocque's 1746 Map of London, historical Ordnance Survey (OS) maps from 1851 to the present day and other reliable information. AKT II have obtained existing drawings of Ludgate House from Sir Robert McAlpine Archives which give an indication of the structural scheme of the building that is arranged on lower ground, ground and eleven upper floors.

After collating all the relevant information from the site, a site-specific constraints diagram is prepared (Figure 3.2.b.1). This document allows the team to coordinate with the rest of the design team, issues such as potential clashes with services, impact on proposed structural system, on massing and interferences.

Figure 3.2.b.1:

The existing Geotechnical report has been received by the client, then this information is reviewed and used to extract the parameters needed for the design of the foundation system and the retaining structure, otherwise a site-specific assessment is requested upon issue of a brief for site investigations. The report includes a description of the various ground layers encountered, including detailed geotechnical aspects test results, interpretative reports (Figure 3.2.b.2).

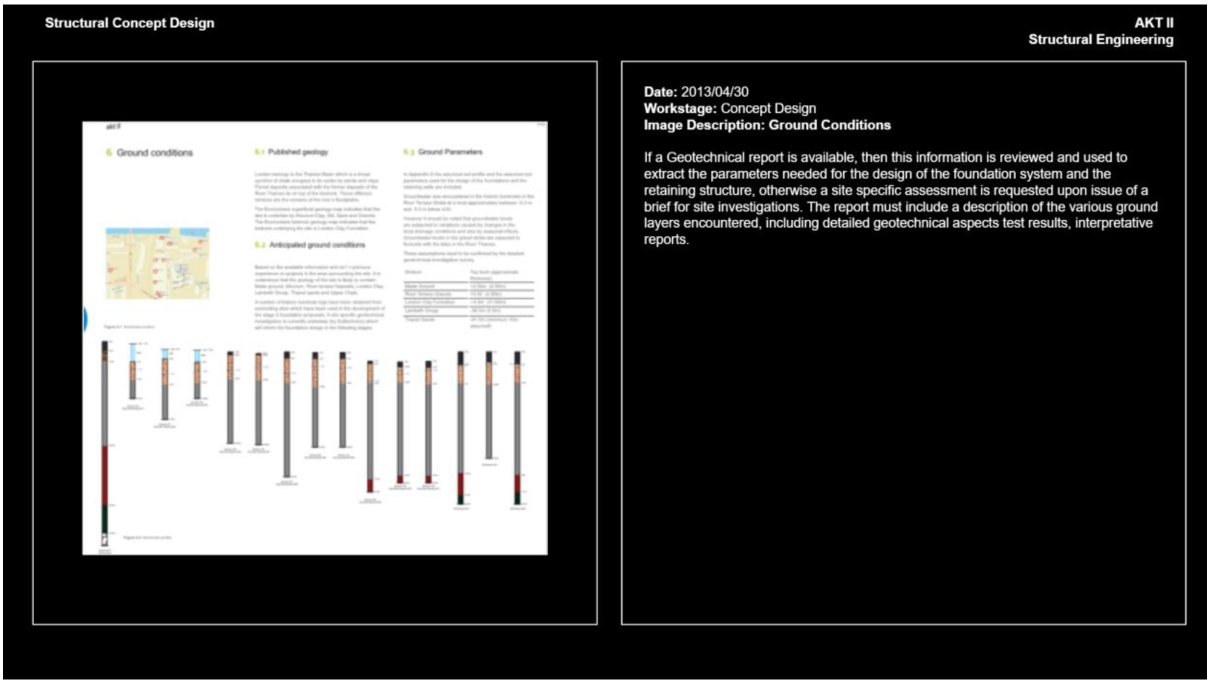


Figure 3.2.b.2: Part of the Geotechnical Report.

On the base of the required use of the spaces and the architectural/client ambitions in terms of finishes/ performance, a definition of loading is then prepared by the senior engineer and his team and documented using codified approach, material characteristics and performance requirements. At this point a draft issue of a document highlighting the basis of design and the main parameters that we are selecting while developing the project (Design Life, loading conditions, reference codes, seismic and wind local parameters etc). To be approved by the client and design team (Figure 3.2.b.3).

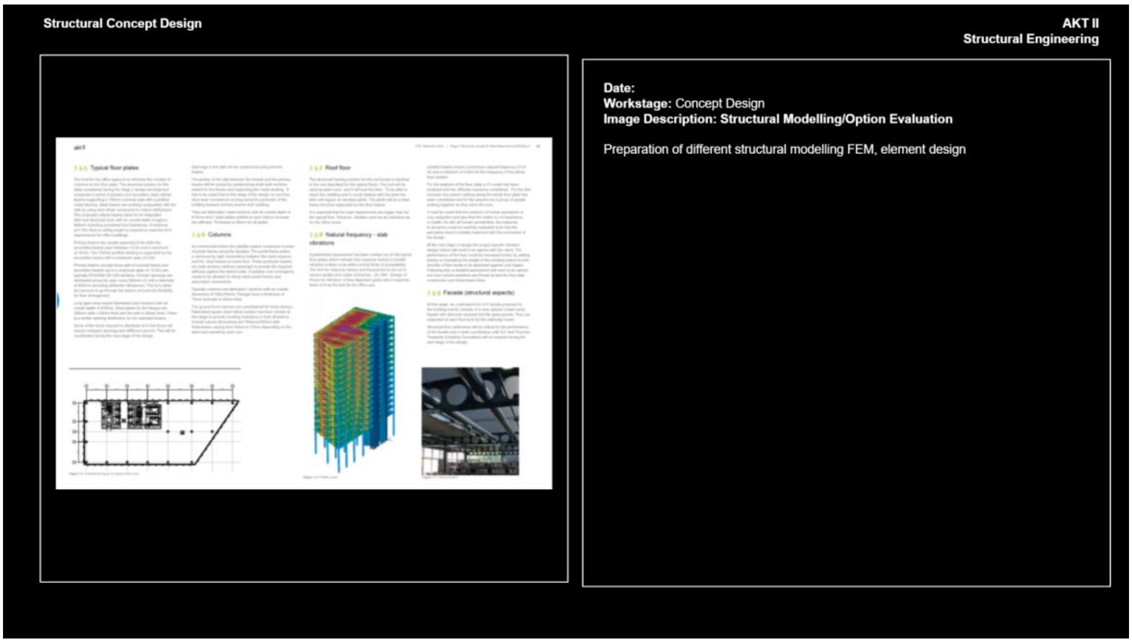


Figure 3.2.b.3: Concept design evaluation.

The structural solution comprises a mixed solution with an in situ reinforced concrete core and a steel frame supporting steel composite cellular beams and a 130mm concrete slab on metal decking. Due to the eccentricity of the core on plan, the building is stabilised against lateral loads using a combination of the concrete core and a series of portal steel frames along the facades.

The size of the structural grid directly influences the floor construction, structural zone, slab thickness, column sizes and foundation requirements. Following initial analysis and assessment, the design has progressed with a primary structural grid of approx. 9.0mx13.5m. However, in some locations the column spacing is irregular and varies to suit architectural/client requirements, this is primarily in the central area in front of the core where the beams span up to 18m to reduce the number of columns in the space (Figure 3.2.b.4).

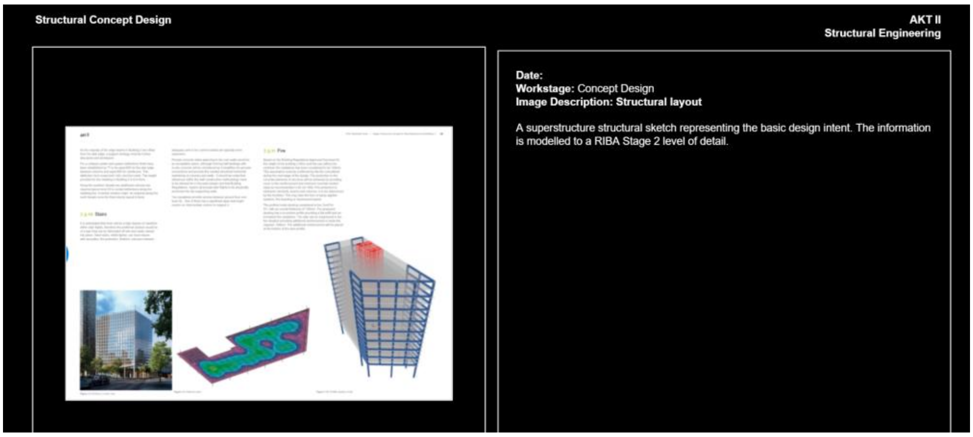


Figure 3.2.b.4: Concept design. Structural layout.

Evaluation and preparation of initial material estimates to be provided for a preliminary cost evaluation to be assessed by the relevant cost consultant, to be updated and included in the final report.

A series of sketches were prepared using Revit and Bluebeam to highlight the different structural options, layouts, findings, those will be then part of the conclusive report for this stage. The cad information is modelled to the appropriate RIBA level of detail. For the purpose of the report a general description of overall construction sequence has been prepared, highlighting the impact of alternative solutions on cost and time on site, also highlighting specific needs in terms of temporary requirements (eg propping and special permits road closures etc.) This has been done using Rhinoceros and Vray, to visually highlight the element in question.

The senior engineer and his team prepared a Risk matrix Highlighting risks and opportunities identified in the current stage with relative levels of importance and mitigation measures (Figure 3.2.b.5). A report is redacted in the last weeks before the issue to compile all the relevant findings, describe the main structural findings, including all the relevant documentations from third parties collected during the phase, illustrating the risks and opportunities and collating all the sketches, drawings, and relevant correspondence for the project.

Figure 3.2.b.5: Highlighting risks in the design and proposing mitigation measures.

The design developed in the further stages with the following main changes. The design has undergone the number of schemes proposed by the Client and developed by the Design Team. The design has been refined for the following changes: At stage 3: Perimeter shift of the columns towards the facade along the East, North and West escalator move in the lobby area at levels Ground to 2. Hub space modifications due to usage as office space and roof space change. These changes resulted in a reduced number of columns within the floor layout and increased area for residential use. The column design has been developed to reduce the number of composite columns without increasing their sizes on upper levels. Floor plates have been designed to accommodate those changes with taking into account deflections criteria defined by the facade consultant. A detailed study has been carried out on the global stability of the building to suit the updated floor plans and to accommodate the wall openings as specified by the architects and MEP engineers.

At stage 4: Vierendeel Portal frame modification. This change has been proposed to accommodate the inset terraces. The vierendeel frame along the south elevation of the BY3 consists of 5 No. prefabricated H-shaped columns with varying thicknesses and horizontal portal frame beams at level 3 and every two floors from level 4. It's to be noted that only 3 out of the 5 columns continue down to the ground floor, the other two columns start from level 3 to the roof. This change brought realignment of structural columns, changes in floor beams depth and the introduction of an asymmetrical beam in the terrace level. Level 2 cut-out area: The cut out area in level 2 has been relocated and modified in geometry, introducing the requirement for a soft spot area, and provoking an update to the steelwork setting out, including additional secondary work around the perimeter of the opening to pick up false floor panels and balustrade. New level 3 overhang: New floor area at level 3 introduced requiring transfer structures in level 2 and 3 stepping areas and also on level 4. Stepped levels geometry between level 2 and 3 has been altered to account for the overhang, provoking an update in the steelwork and floor structure. Level 18m office extension: New floor area has been introduced between L18 and L18m, which is supported by a new transfer beam on L18. Level 19 and 20 modification. A stepping on L19 and L20 has been introduced, requiring cantilevering beams, and a future infill also required and allowed in structure capacity.

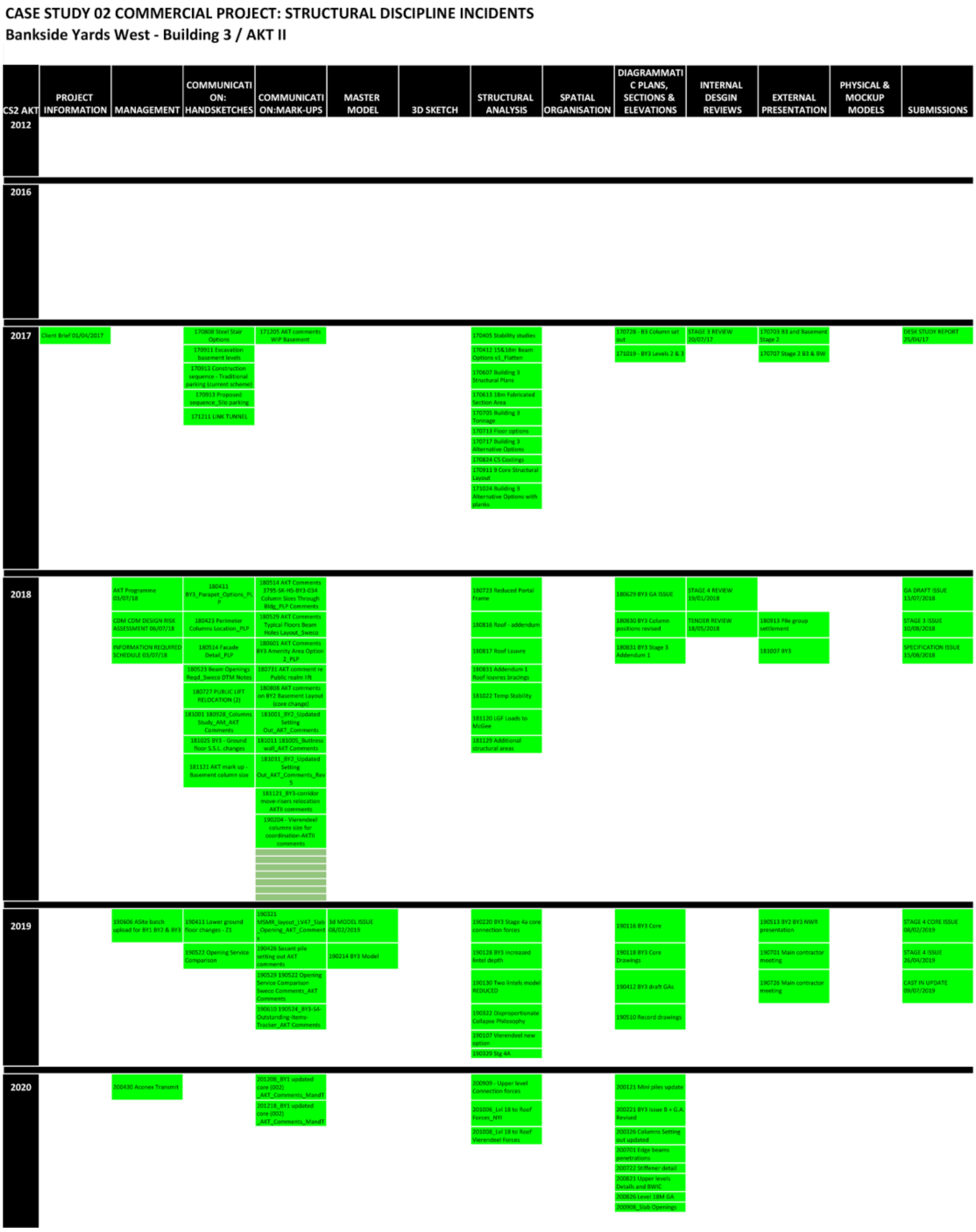


Figure 3.2.b.6: Incidents during the structural design. Higher resolution / excel sheet

3.2.c CASE STUDY 4b: MEP: Bankside Yards West - Building 3 / Sweco

Bankside Yards Building 3 (BY3) is a 19 storey office building under construction by Multiplex PLC in the Bankside area of Southwark, London. Designed by PLP Architects, it forms part of the Western Yards development that also comprises two residential towers with a 4-storey common basement. The office building comprises 14 flexible office floors, an executive floor at the top of the building which has increased volume and a mezzanine level, and an Amenity Hub, which is a double-height space with occupiable stair landings connecting levels 2 & 3. The building is served by a double-height reception, the soffit of which extends out over Invicta plaza to the south. SWECO was appointed directly by the client for this project. The project was developed by a team of 21 professionals, including Project Director, Project Manager, MEP Leads (Mechanical, Electrical, Public Health), Design engineers (Mechanical, Electrical, Public Health, Sustainability), BIM & ITAC Specialists and technicians.

The main communication method with the client and architect consists of emails and regular meetings. Internally SWECO utilises Bluebeam Revu and BIM360 for mark-ups. Externally, the mark-ups and sketches are communicated via online platforms i.e. Aconex in accordance with document control protocols set and managed by the main Contractor.

Client/Architect presentations and design workshops/meetings are organized as required to assess options suitable for the project. Several presentations are also deliberated internally to design teams and externally to architect/client after the completion of each stage to inform of services designed, in addition to MEP services presentations to Building Controls for approvals.

Technical Innovation

The closed cavity façade on the building has been developed to limit heat loss and control solar gains whilst providing near uninterrupted views across London. The design incorporates a blind system that monitors and tracks levels of solar radiation and adjusts the position of the blinds accordingly, ensuring that the highly transparent glass desired works in conjunction with the building's heating and cooling systems. BY3 is designed to operate as a low energy, highly efficient building. It incorporates emerging technologies such as low carbon air source heat pumps as opposed to gas-fired boilers which reduces the carbon impact of the building.

Project Timetable and incidents

SWECO were involved from the early stages with the Bankside Yards development and helped the architect with the initial planning application, before developing and submitting a Stage 2 package during late 2017. The first major design change occurred during stage 3, by which the roof plant area which was initially one level was reduced to allow for level 18 office space to be converted from a typical level to a more executive level with a mezzanine and sloping ceiling. The change introduced an additional plant level at level 18M where the air handling units providing tempered fresh air to the office demise were to be located. The final stage 3 design was submitted in August 2018.

After stage 3, a major change to the basement was required to accommodate the UKPN 33 kV route. The change caused multiple coordination difficulties requiring all previous modelling works to be scrapped, and the design was redeveloped from scratch. This experience offered a chance to learn considerable lessons when working in the 3D environment about modelling in too much detail too early. SWECO continued to develop the design during 2019 working towards a May 2019 issue for the full tender package for the shell & core and CAT A fit-out.

During Early 2020, Multiplex as the appointed contractor raised to the client a potential VE option that would replace the Combined Heat and Power (CHP) energy centre and gas boilers with stand-alone 4-pipe air source heat pumps, providing LTHW (Low Temperature Hot Water Heating) and CHW (Chilled Water) to serve the buildings heating and cooling demands. SWECO developed this proposal in a short six-week design stage into a full tender package ready for issue in March 2020.

During the construction phase of the basement, the contractor raised a potential issue where a secant pile wall, erected as a temporary measure whilst existing local infrastructure is rerouted around the basement box, would not be removed in time to allow life safety plant rooms, required to be operational, to be installed in time to meet the expected BY3 practical completion. During late 2020 SWECO within an eight week period again redesigned the basement to move wet riser and sprinkler rooms further south and hence clear of the secant pile wall where they could be completed in time for PC.

A further design change was instructed in late 2020 whereby CAT A was omitted from the office floors except from floors 4,5,10 &16. SWECO were therefore instructed to review the design and ensure all minimum requirements in terms of emergency lighting, fire alarm and fire protection were complied with.

Technical Challenges:

The design of the BY3 eludes to many significant engineering challenges. The building is designed to cantilever over Invicta Plaza, which means that despite a significant area of the office floor plate existing at upper levels, the core and therefore a significant portion of the risers do not extend to the basement. This meant that the services had to be very carefully coordinated to maximise the efficiency of the riser space that was available and minimise offsets at upper levels which could impact the experience of the building.

Between stage 3 and 4 a planning stipulation was introduced, which significantly reduced the ability to utilise roof plant space. The majority of the BY3 major plant is located on the level 19 roof; however, the planners did not want this to be visible from ground level which meant a major reconfiguration of the plant was required and subsequently called for the roof slab to be increased to ensure all plants could be accommodated.

Electrically there was a significant engineering challenge to route the UKPN 11kV cables into both the residential and commercial. The requirement from UKPN was that all the UKPN cables should be routed through steel pipe as it was routed through the landlord areas and any locations which needed cable access chamber was coordinated with the structural consultant and was made available through landscaping areas. SWECO played a lead role in coordinating route architectural structural and other stakeholders. These incidents are described in great detail in the following figures. Several figures were blurred on purpose due to security reasons. The reviewers can contact the project authorities for better quality images.

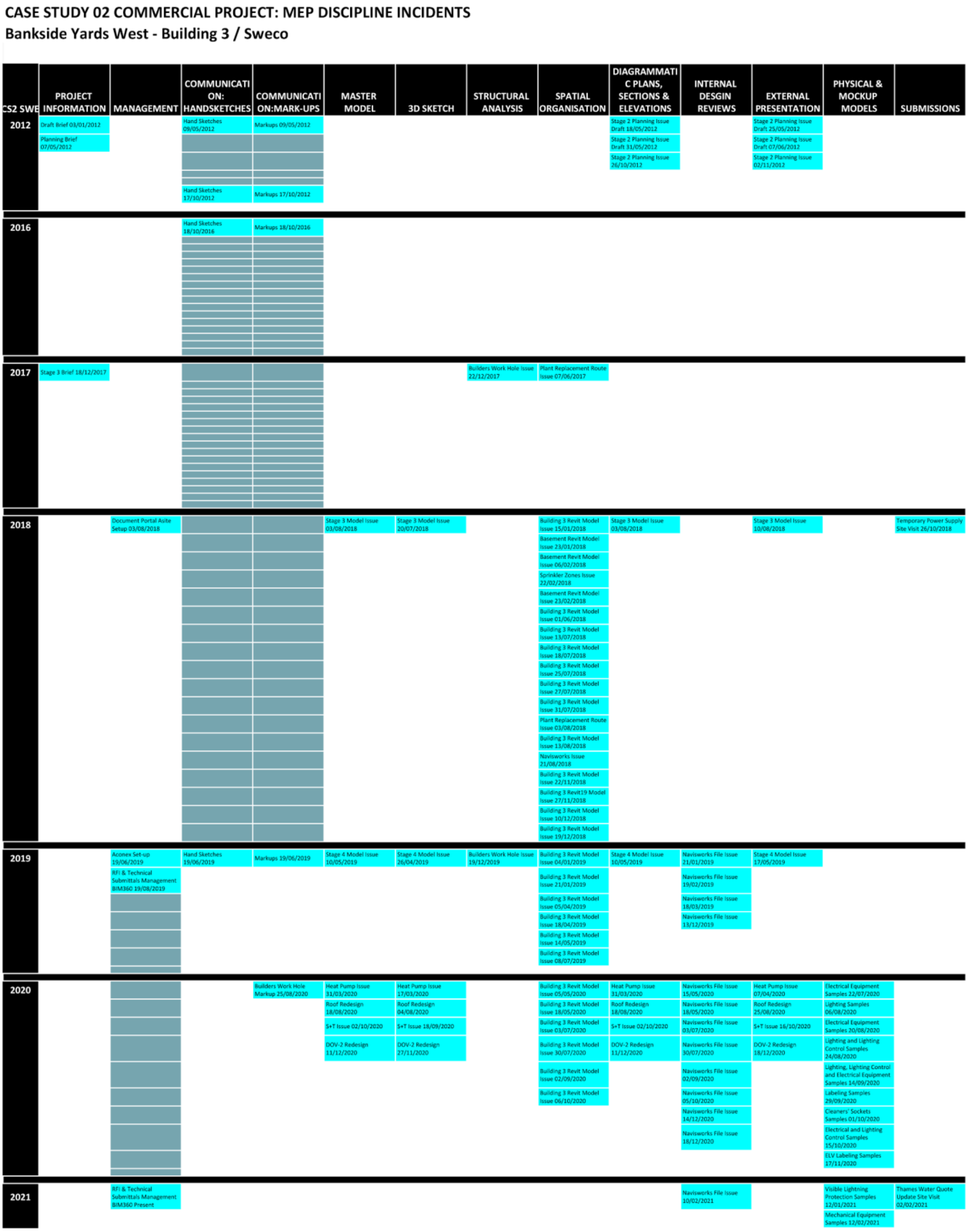


Figure 3.2.c.1: Incidents during MEP design of BY3 building.

Higher resolution / excel sheet

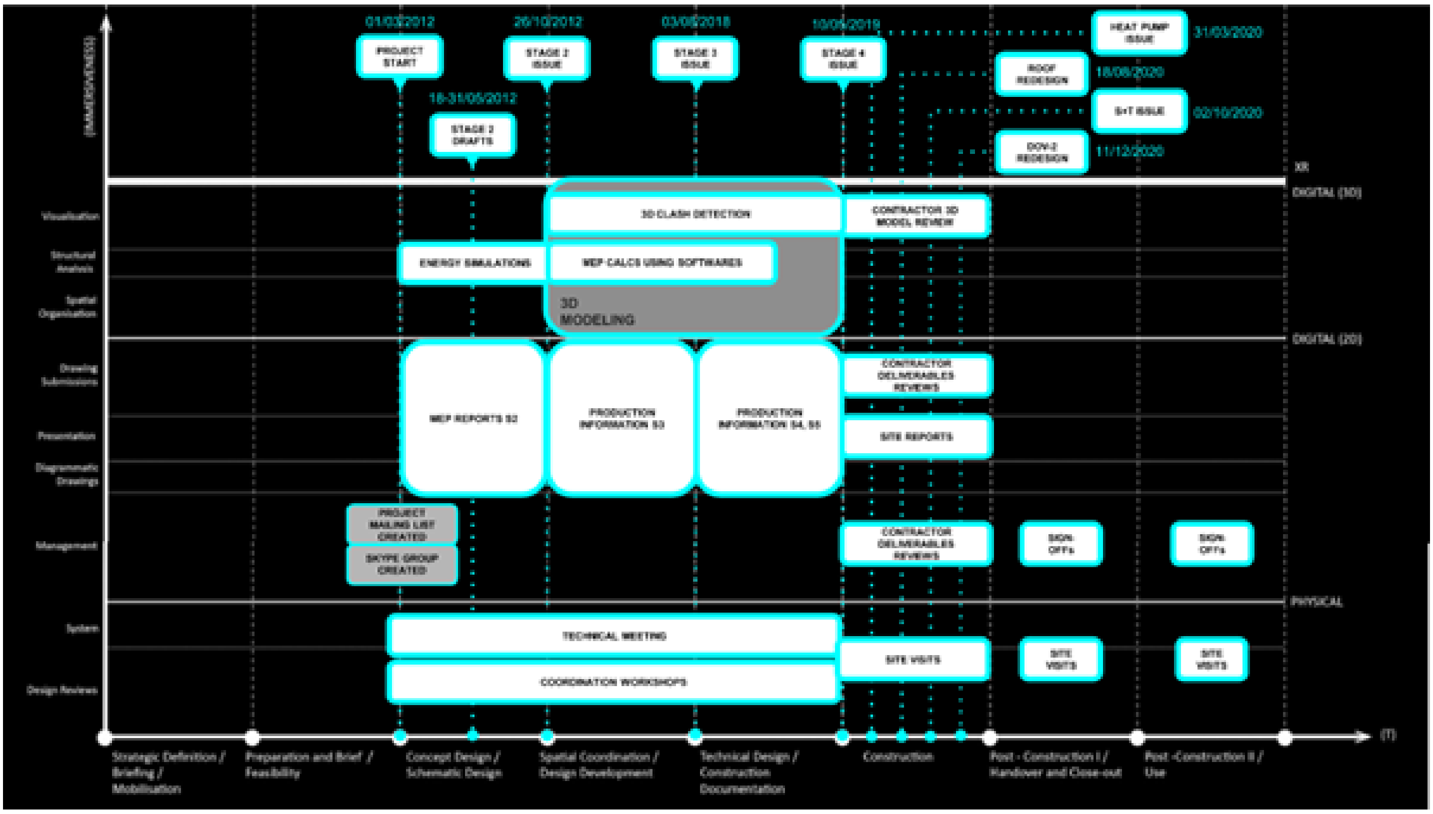


Figure 3.2.c.2 - The timeline of the MEP design development

Figure 3.2.c.3 - Sample building external analysis (blurred on purpose)

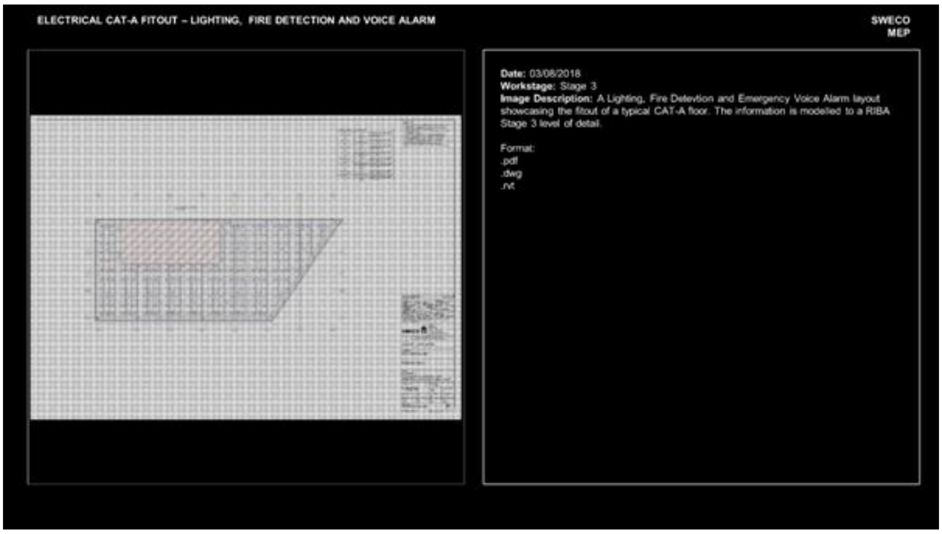


Figure 3.2.c.3 - Typical stage 3 Electrical Layout (blurred on purpose)

Figure 3.2.c.4 - Typical Stage 3 Mechanical Layout (blurred on purpose)

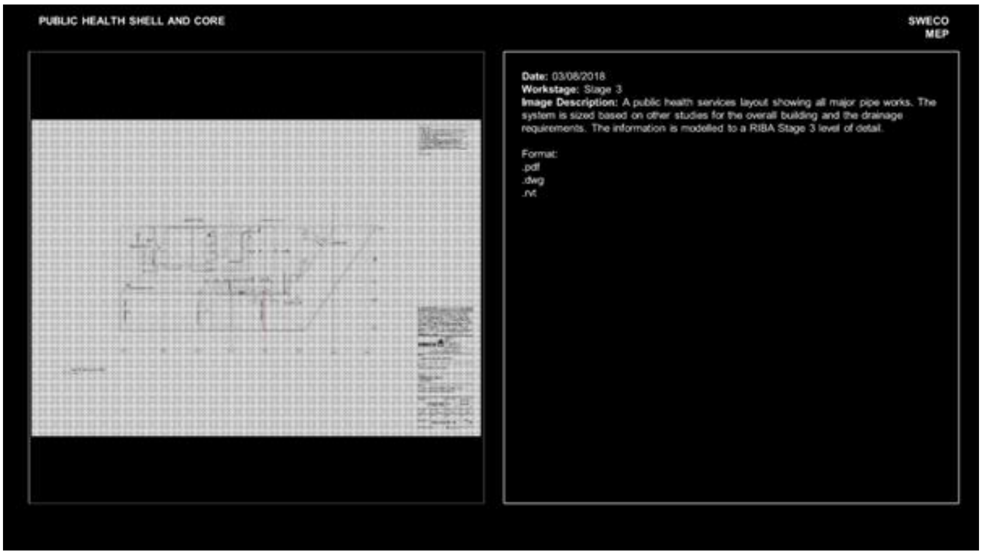


Figure 3.2.c.5 - Typical Stage 3 Public Health Layout (blurred on purpose).

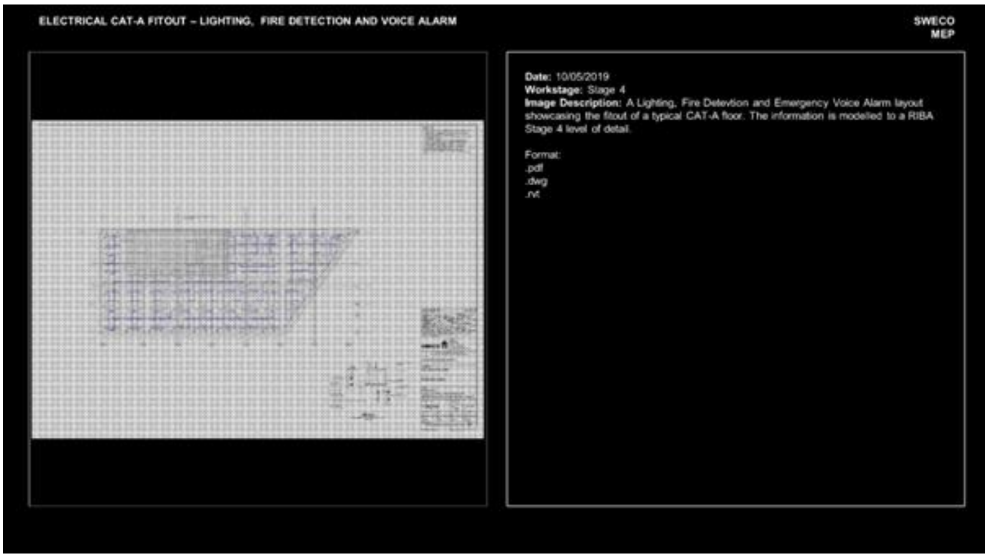


Figure 3.2.c.6 - Typical stage 4 Electrical Layout (blurred on purpose).

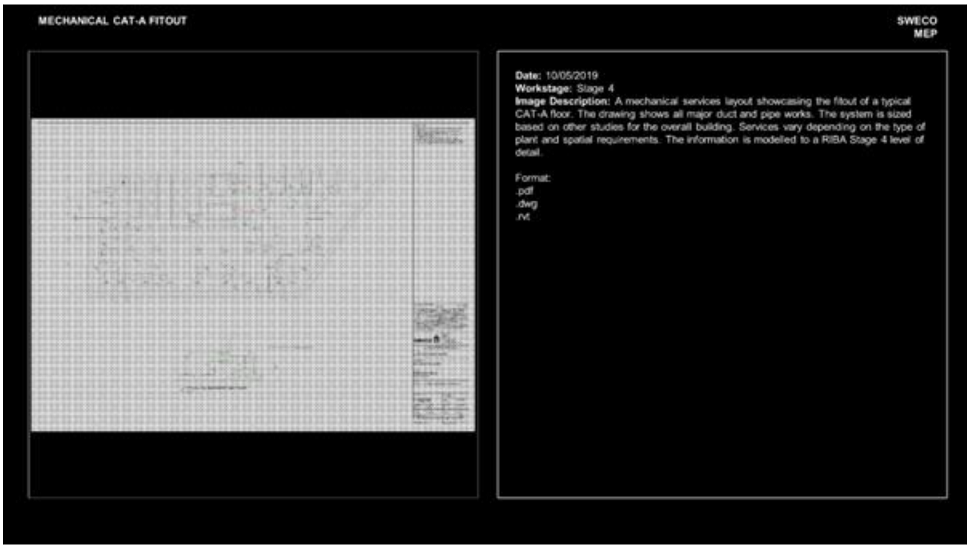


Figure 3.2.c.7 - Typical Stage 4 Mechanical Layout (blurred on purpose).

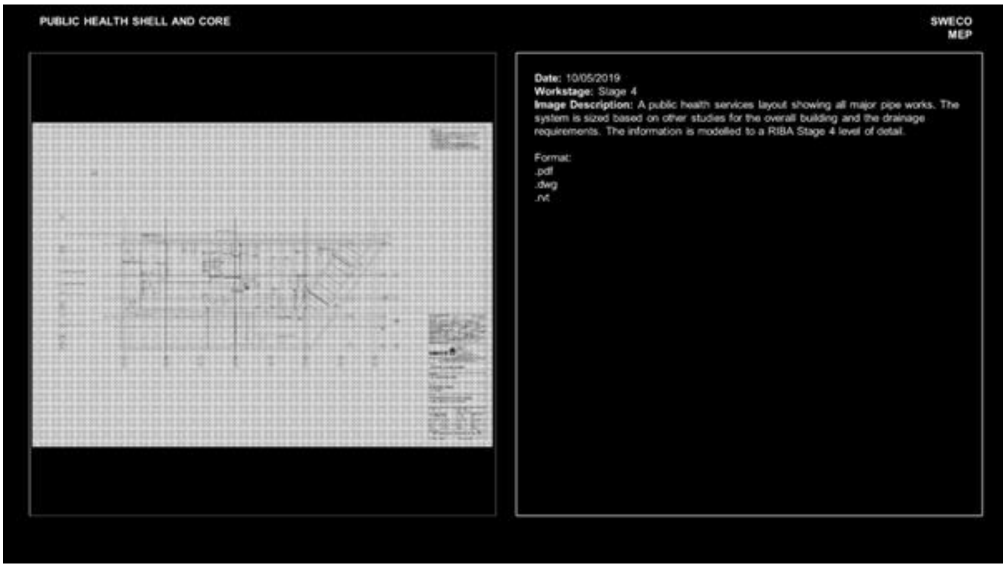


Figure 3.2.c.8 - Typical Stage 4 Public Health Layout (blurred on purpose).

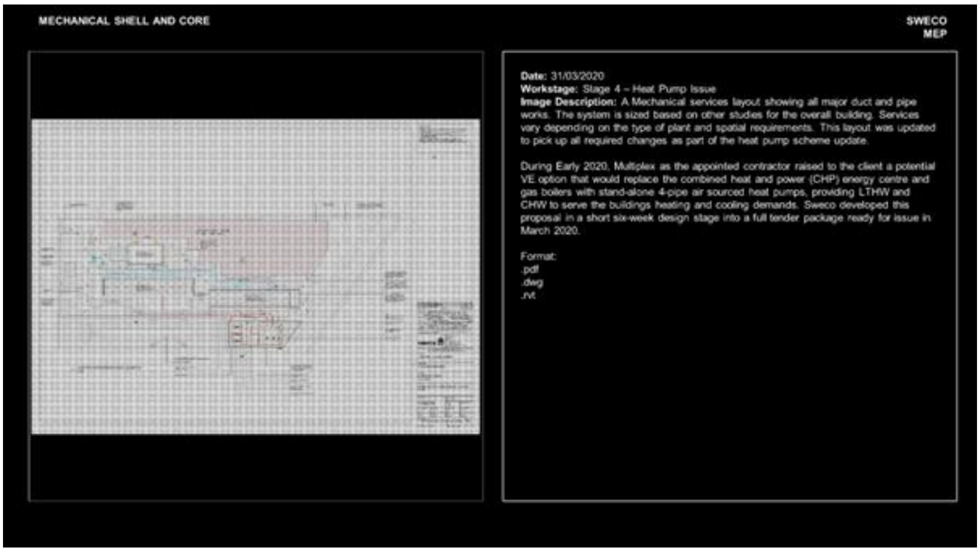


Figure 3.2.c.9 - An update to the mechanical design as part of the Heat Pump Issue

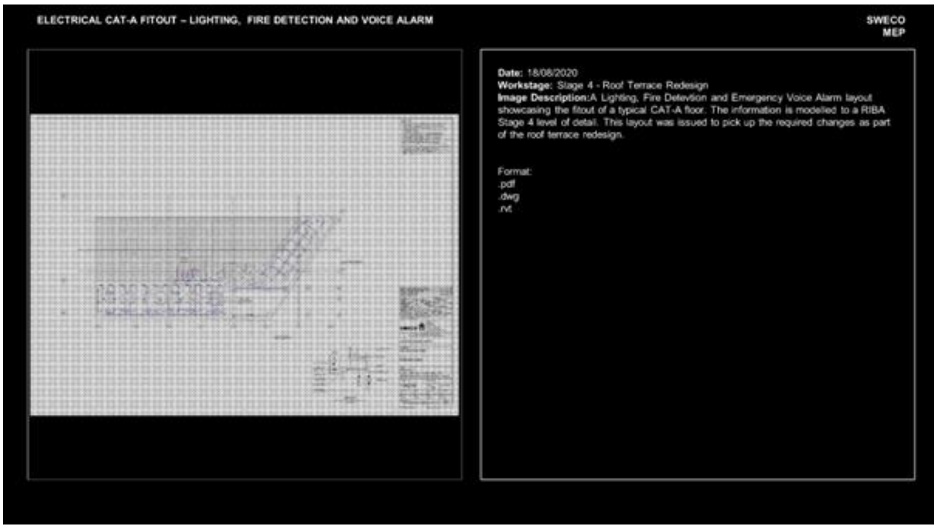


Figure 3.2.c.10 - An update to the Electrical design as part of the roof terrace redesign

Figure 3.2.c.11 - An update to the Mechanical design as part of the roof terrace redesign

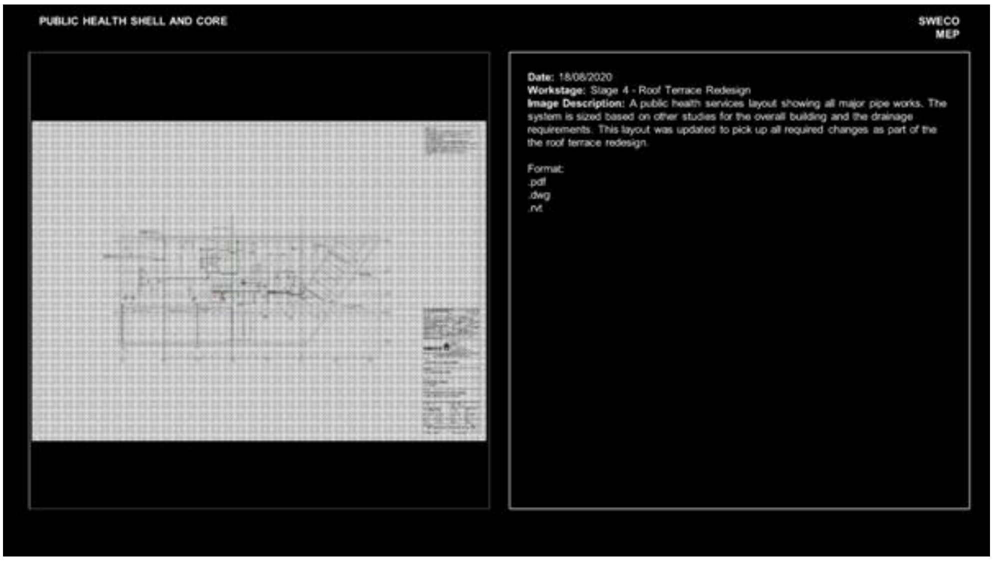


Figure 3.2.c.12 - An update to the Public Health design as part of the roof terrace redesign

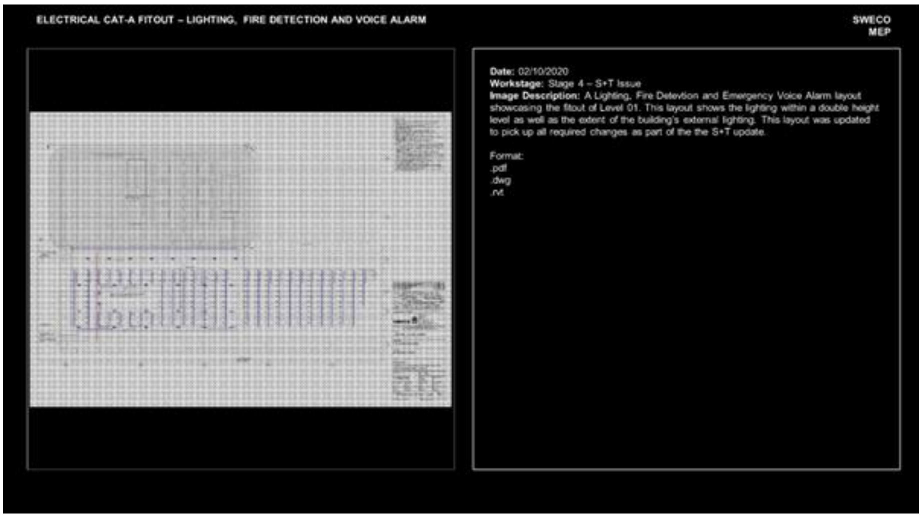


Figure 3.2.c.13 - An update to the Electrical design as part of the S+T Issue.

Figure 3.2.c.14 - An update to the Public Health design as part of the S+T Issue

Figure 3.2.c.15 - An update to the Electrical design as part of the DOV-2 Update.

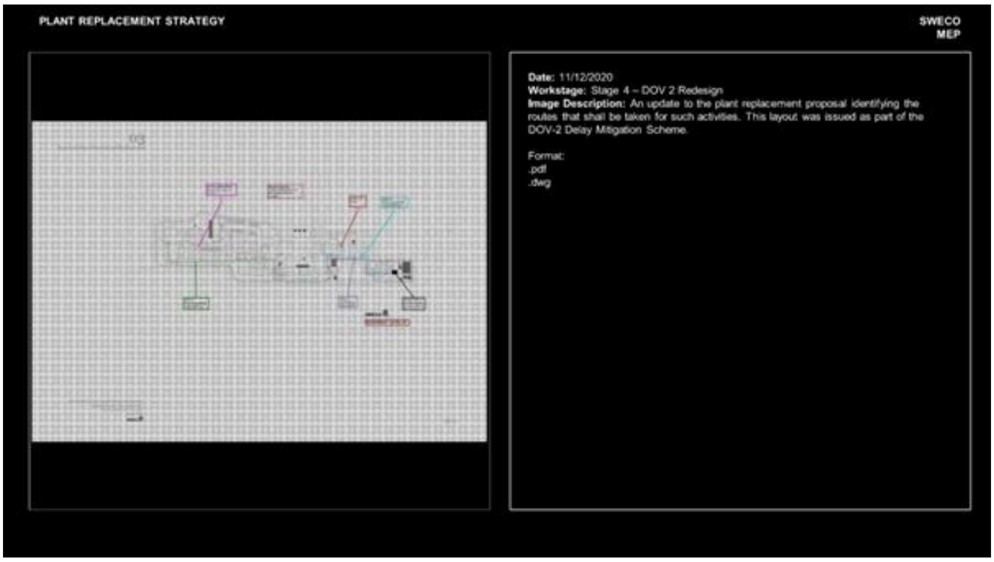


Figure 3.2.c.16 - An update to the plant replacement strategy as part of the DOV-2 Update.

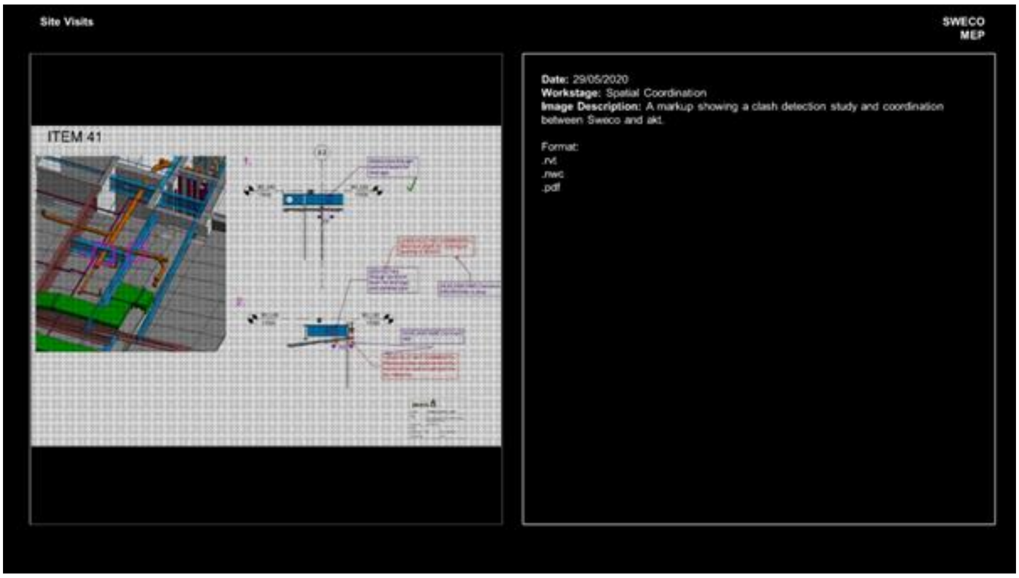


Figure 3.2.c.17 – A clash detection process between different disciplines.

Figure 3.2.c.18 - Pictures taken from a physical site visit (blurred on purpose).

3.3 Case Study Conclusion

Discipline Commonalities:

- Each individual discipline produces feasibility studies prior to proceeding with contractual agreement
- Documentation and production is coordinated and reviewed at every stage of the project. The coordination is usually carried out by the architect
- Hand Sketches and diagrams are commonly used across the stages. The resolution of the information contained in the sketches increases along with the project development
- Creative thinking and problem solving
- Task distribution depends on the project resource's skill sets. The list of project members is added as part of BIM project information requirement
- Arranging discipline-specific workshops
- Documenting individual decision-making paths
- Preparing and submitting discipline-specific drawings
- Requiring approval from Project Director prior to submitting drawings
- Commenting on and reviewing internal production
- Presenting and sharing updated production with other disciplines
- Compiling multiple 3D assets designed by different authors (internal or external)
- Visualisation used for communication of aesthetics and information, and for coordination purposes
- Using references to previous projects (formal, geographical, technical and system principles, office resources, contractual setups, budget...)
- If there are no market-available tools for a specific task, each discipline would develop their own tools for in-house use (R&D)

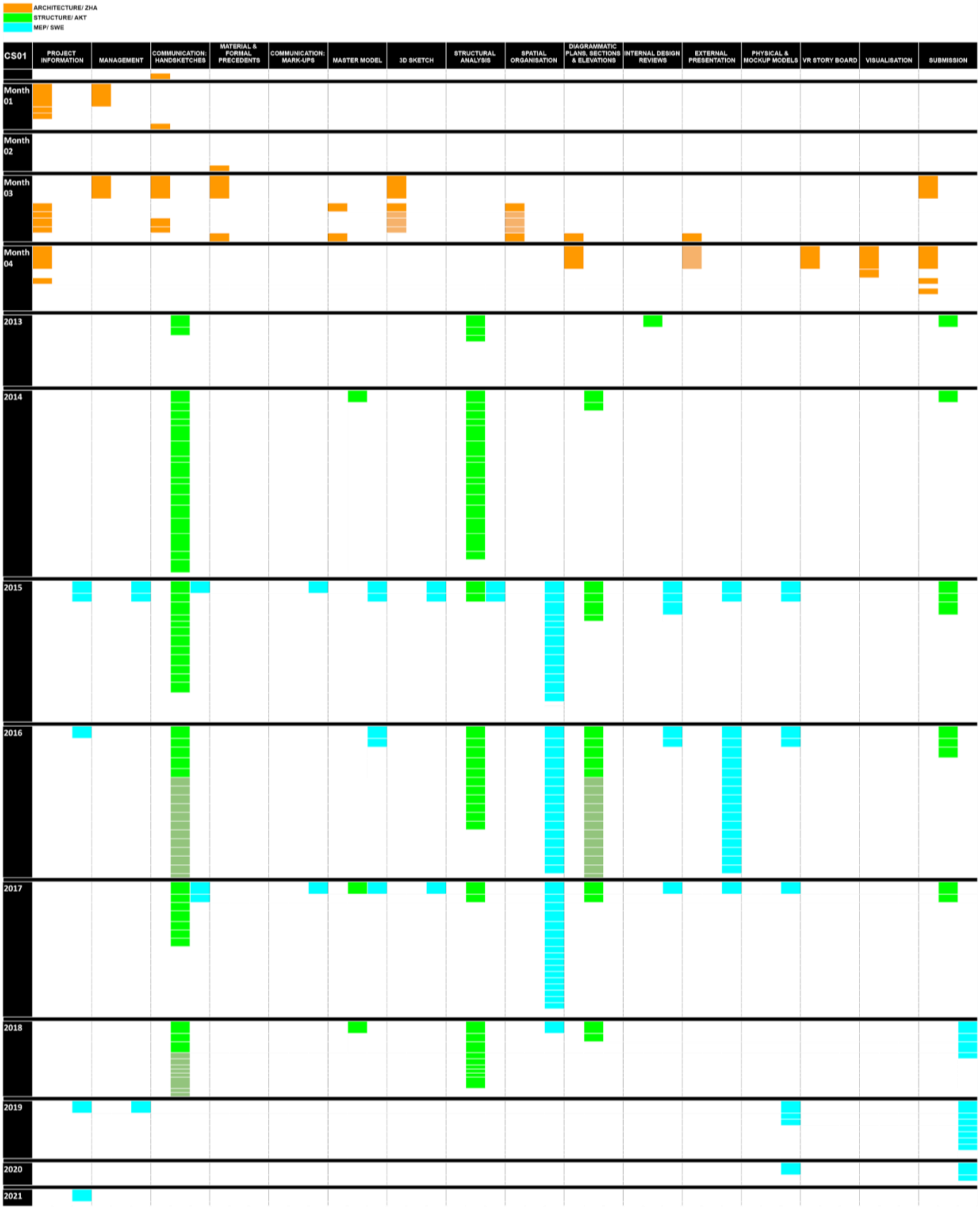
Discipline Differences:

- Project start point is different for all disciplines (appointment date is the individual start date)
- Architects use 3D modeling tools as a formal and cultural brainstorming tool, while -Engineers use the modelling tools to assess the 3D model. Structural engineers model structural components for testing. MEP Engineers rely mainly on an extensive BIM library, and do not model as many components in 3D for each project.
- Both Architects and Structural Engineers do site investigations. However, the resolution of the information gathered on site is different, and this information is used in different ways. Site photos are mostly used by architects to understand the area, its constraints and any existing formal context. Structural engineers use the materials gathered on site to highlight problems and design the foundational principles for their structural analysis. Engineers require further site investigation in the construction mobilisation stage (e.g. basement, existing soil or site specific condition)
- Within the architectural discipline, naming conventions and their set up are project-specific at the early stages. There are CAD naming standards, but they are not usually used until the documentation stage, later on in the project development. The early naming conventions used in architecture might follow the pre-set system within project files for BIM based project files.
- In the presentation, architects describe aesthetic and cultural aspects of the project. Structural and MEP engineers, on the other hand, are required to present numeric data, design parameters and solution-based content.

In the following figures we have assessed collective project planning for the commercial and residential use cases that will be used during the project.

Collective incident distribution map for the residential case studies

Higher resolution / excel sheet



Collective incident distribution map for commercial case studies

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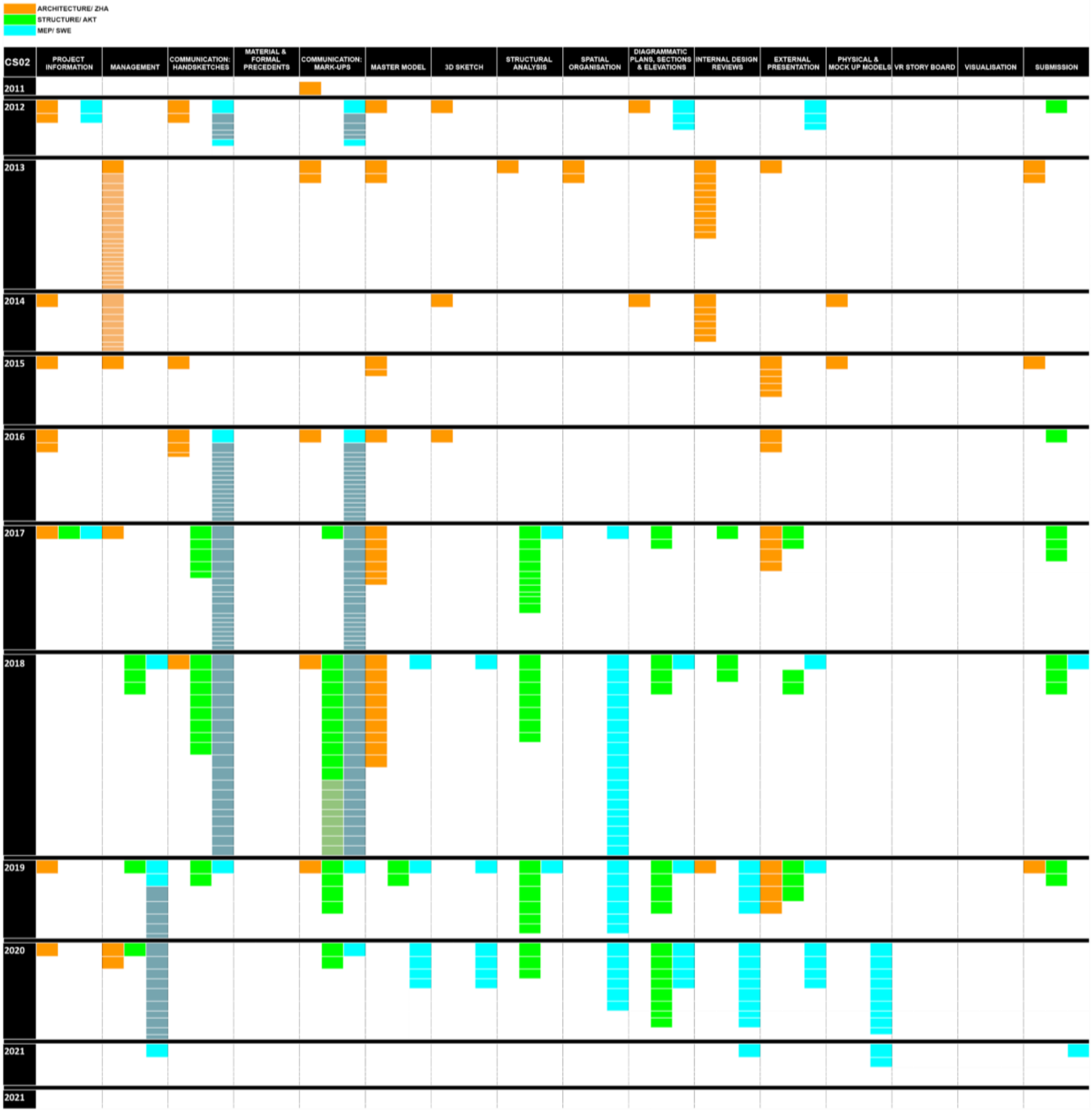


Design inspiration and its impact on development

Design inspiration is a project-specific factor. The project sometimes might be required to be explained in an abstract and artistic manner when architects present the project concept to the clients (Example 1). Setting a narrative and telling a project story can help the clients to explore the ideas and give inspirations. On the other hand, project inspirations can also be delivered from mathematics, physics or technical innovation such as environmental analysis including wind load and solar radiation (Example 2 and 3). PrismArch platform should be aware of the fact that the project inspiration parameters can vary and the terms should be flexible and these might include cultural, experiential, personal, environmental, economic, technical or mathematical terms.

Sharing the initial design inspirations also help engineers to understand the brief in depth and to highlight potential design problems and their solutions. Involvement of both aesthetical and technical perspectives at an early stage can enhance the communication between disciplines and also can help to avoid the risks of changing options at later stages (Example 4).

Example 1 (Private Residential Villa, ZHA)

"The connection between inside and outside is preserved through generous glazing and sheltered outdoor areas, and the interior and exterior designs were merged into a singular sculptural form. The brushed stainless-steel facade highlights the sweeping architectural lines, while giving the building a sleek and futuristic style. Light reflects and glitters on the facade, giving the impression of stepping into a sculpture which hovers above the ground."

Example 2 (One Thousand Museum, ZHA)

"Miami experiences seasonal hurricanes, so the building was designed to withstand winds of up to 180mph. Constructing the 216m tall concrete exoskeleton to precision, at height, and to a demanding construction program was also a challenge that required collaboration, testing, and an innovative technical solution."

Example 3 (One Park Drive, SWE)

"Due to the height of the building, it was necessary to provide two hydraulically independent circulating systems serving low and high zones for both LTHW and CHW within the building in order to limit the pressure rating to PN16 at the residential interfaces."

Example 4 (One Park Drive, SWE)

"Given the building's slenderness ratio, the available plant room space within the basement was moderate compared to buildings with larger floorplates. This creates numerous coordination difficulties and with space at a premium careful and accurate multi-discipline coordination from an early design stage was essential."

Cross disciplinary communication before BIM system implementation

Disciplines are appointed according to different timings. In most cases, architects are appointed at the beginning of the project by the clients and work to define the project brief and brainstorm the project concept together with the clients. In order to propose a few geometry options that reflect the clients' requirements and present the visual and aesthetic qualities of the building, architects typically carry out massing studies using 3D modelling tools prior to sharing these ideas with engineering disciplines (Example 5) . Once decisions are made internally and a few selected options are adequately prepared, architects would contact the structural and MEP engineers to understand the feasibility and cost of the project. The project-specific option names are often used for communication purposes and for file names, and these option names can also be extended to be used across disciplines and the clients to distinguish characteristics of the options in the project concept stage (Example 6). AKT II mentions in Chapter 2 that one of the responsibilities of structural engineers is to understand the project brief developed by the architects and the clients and to support the disciplines by reviewing the contents and designing structural principles following the proposal (Example7).

In an early stage of the project development, cross-disciplinary communication mostly occurs between the clients, architects and structural engineers before the final design option is selected and before the 3D models are rationalised and handed over to other disciplines.

Example 5 (Private Residential Villa, ZHA)

"The project team had three 3D designers to produce architectural geometries. Each member worked individually using their own work environment (software, PC spec, folder structure etc) to produce several massing options. The project team produced a total number of 25 massing options, initially starting from 10 options, and selecting one building and one landscape massing option followed by 3 sub selected building options. Daily reviews were organized between the 3D modellers and the project directors"

Example 6 (Private Residential Villa, ZHA)

"The designers gave unique names for each option ("Vertical", "Palazzo", "Loops", "Tetris", "Disks", "Cube Blend," "Cube Stretched" for the building, for the landscape: "Double Pivot", "Techno", "Vectors", "Pixel"). Designers used these names in the file name with dates in their production folder (i.e.) 200515_Loops.mb, 200518_strands.mb. These names were also commonly used in design reviews with the project director. "

Example 7 (One Park Drive, AKT)

"... early CAD drawings, site material, investigations, photographic surveys, digital surveys etc are reviewed to understand both the existing conditions and the Architectural intent. In this instance, we have supported the Client and the architectural team in developing the first massing ideas."

Architectural 3D models have different resolutions. In the case study of the One Thousand Museum project developed by ZHA, it can be seen that the resolutions of the utilised 3D models are evolved over stages and used for different occasions and purposes without implementation of the BIM system. For cross-disciplinary communications with structural engineers and MEP engineers, the initial 3D models were rationalised and optimised. After the correspondence for the spatial coordination, 2D drawings are made based on the model and these were compiled into documents for the planning submissions. It is stated that the architectural team did not include some of the prepared drawings for the submission and not all produced drawings are used at the construction stage. This suggests that unfolding the complexity distribution of the construction, structural and MEP complexities at an early stage of the project development can help architects to focus on only the required area of the building, and this also helps reduce production time.

Expected and unexpected risk management at a later stage of the project development

All disciplines have responsibilities to predict, list, avoid and manage any potential risks with the application of the expertise knowledge (Example 9).

Example 9 (One Park Drive, AKT)

"The senior engineer and his team prepared a Risk matrix Highlighting risks and opportunities identified in the current stage with relative levels of importance and mitigation measures." "A Stage C report is redacted in the last weeks before the issue to compile all the relevant findings, describe the main structural findings, including all the relevant documentations from third party collected during the phase, illustrating the risks and opportunities and collating all the sketches, drawings, and relevant correspondence for the project."

Risk management is expected to be considered at all stages of the design development. Building regulations are reviewed and changed by the local government regularly, influenced by social and cultural matters. Architectural design must adapt to these changes dynamically. In the case of Example 10, due to a change in the local regulation, architects had to access and modify the completed model at the construction stage to amend the slab design. Since the final model was changed, submitted drawings also needed adjustments in response to the changes. This specific case study did not implement the BIM system, yet even if the system was implemented, the 3D model adjustments had to happen inside the 3D model with lower design resolutions. This means that the project needed to be downgraded to make changes and they would need to access the multiple software again to essentially create a new BIM 3D model.

Example 10 (One Thousand Museum, ZHA)

"Another significant change stemmed from insurance requirements due to **new regulations**, requiring the ground floor level to be moved to +10. A plinth had to be designed to negotiate between the existing grade and the ground floor. The changes introduced numerous adjustments to the entire tower. As a result of moving the ground floor and requiring more height on level 8 and level 9, 1" or 2" was removed from a series of levels and redistributed to the podium levels. **This involved Adjusting the glazing line setting out on every level, remodelling portions of the exoskeleton, and adjusting all sections.**"

Example 11 (Bankside Yards West - Building 3, SWE)

"After stage 3, a major change to the basement was required to accommodate the UKPN 33 kV route. **The change caused multiple coordination difficulties requiring all previous modelling works to be scrapped, and the design was redeveloped from scratch. This experience offered a chance to learn considerable lessons when working in the 3D environment about modelling in too much detail too early.**"

Example 12 (Bankside Yards West - Building 3, SWE)

"During the construction phase of the basement, the contractor raised a potential issue where a secant pile wall, erected as a temporary measure whilst existing local infrastructure is rerouted around the basement box, would not be removed in time to allow life safety plant rooms, required to be operational, to be installed in time to meet the expected BY3 practical completion. During late 2020 Sweco within an eight-week period **again redesigned the basement to move wet riser and**

sprinkler rooms further south and hence clear of the secant pile wall where they could be completed in time for PC."

In the example 11 and 12, the MEP team was involved in the project development from an early stage, however, the developed 3D model had to be reproduced from scratch at the construction stage to accommodate the new 33kv cable route of the UK Power Network. The project team lost the 2 stages' worth production time and cost and had to add another 8 weeks to the timeline to redesign and reproduce the 3D models. This example shows a risk of involving multiple disciplines from an early stage of the project development. PrismArch platform must be aware of this risk and the distribution of responsibilities must be carried out carefully, and it can be clearly said that contractual agreements and authorities should be reflected in the platform design.

In the 2 case studies provided by structural engineers and MEP engineers, both authors mention that 3D modelling tools are used only to access updated 3D models from architects; their relative data was translated to BIM to rationalise the design. The above incident examples, however, show that accurate 3D models do not avoid all risks due to unexpected events occurring in real-time. It can be said that identifying and communicating the risks at any stages, and promptly being able to report the issues will help all disciplines to take prompt actions to solve the issues.

Client decision-making impacts to the project design development

Client decision-making has great impact on the entitle life cycle of the project, and is the driver of the discipline production loop. Any plans of changing authors and their responsibilities, and on how the project is to be delivered depend on the clients' requirement and essentially how the project is set up in the contractual agreement. In example 14, it can be seen that the clients also make decisions on taking a risk to complete a project with innovative technology. It is, therefore, clear that clients and stakeholders must be treated as equally as the architects, structural engineers and MEP engineers inside the PrismArch platform, clearly following the authority guideline setup in the contractual agreement.

Example 13 (One Park Drive, SWE)

"The client decided to switch the interior designers for the apartments and appointed three new interior designers for the three topologies of the building. The client tried to shield the interior designers from each other to avoid influencing one another. SWECO was tasked to coordinate with the interior designers and developed comprehensive production information over months spanning from June 2015 to April 2016."

Example 14 (One Thousand Museum, ZHA)

"ZHA had initially suggested pre-cast GRFC formwork for the structure of the building, having investigated this system for a prior project, highlighting its time-saving and quality-control benefits on site. However, because this system had not been deployed previously in the USA, it provided a legal risk to the owner. Having worked to optimise the geometry for a more commonplace cast-in-situ concrete formwork solution, there was a change of directive: one of the main financial backers made a strong case for accepting the risk, and it was decided to proceed with the innovative GFRC precast formwork for the building. (CS2)"

Discipline parameters

Table 3.1 below summarizes the documentation types for each discipline and the design parameters used to guide the design decisions. It also provides an overview of the use of BIM in the four case studies.

Table 3.1: Summary of Case Study design parameters & BIM use across the three disciplines.

	ARCHITECTURE	STRUCTURE	MEP
Documentation	Concept Design package Schematic Design package Design Development package Planning application Tender documentation	Stage C report CAD information modelled to RIBA stage 2 Risk Matrix BIM document	Stage 2 package Stage 3 package Stage 4 package BIM document
Design Parameters	• Design inspiration varies (cultural, construction method, computational tools, local regulations ..) • Contractual setup •Project briefs developed with the clients • Circulation, Programme, Zoning •Site investigation with 3D models and photos • Weather, Geographical info • Material choice • Cultural and aesthetic thinking + input (moodboard) • Modify architectural geometries • Preparing and submitting detailed drawings • Site Visits & supervision	• Safety and durability • Structural performance - load, stress and strengths of structure and materials performance and characteristics, beams, columns and foundations • survey of the built sites to check sustainability consideration value, design, programme quality, adaptability, buildability and health and safety issues • detailed geotechnical aspects test results, interpretative reports	•Building height ratio, environmental data • Basement space planning • Traffic and logistic planners • Landscaping and public realm ventilation openings to spaces below ground • Rainwater attenuation and storage • Sub-slab drainage • Riser and distribution zoning • Low and zero carbon systems (LZC) integration • 3D model / building information modelling (BIM) • Construction programme and cost plan •electrical distribution •lighting requirement

Use of BIM	• No BIM	• Exchange file formats • Register and select object libraries • Setting out datum points • Coordinate systems • Geographical systems. • Creating corresponding naming and classification conventions along with the drawing numbers • Designing protocol to control how the information is used and distributed • Protecting the model and creating the delivery table	• Project Information (necessary information about the project such as Project Owner, Project name, Project Location, Project Description, Project duration, Contract type, Cost, etc.) • BIM Project team Directory (All the project members' contact details such as company name, Name of the individual, email, phone number, and responsibility shall be listed here in the form of a table) • Design Stage Milestones (start date and completion dates) • BIM Roles and Responsibility (Client's BIM representative, Consultant's BIM Manager, Architecture BIM Manager and BIM Coordinator etc.) • Design BIM Goals and Authorized Uses (Visualization, Design authoring, 3D coordination, Digital fabrication etc. It also provides information about Authorized uses. • Model Types and details (Design Intent Model, Contractor's Model, As-built model or Record model. Model sharing platform, model exchange frequency, milestone, file types, software programs used, software versions, shared coordinates, naming conventions) • Digital Collaboration (BIM360 (or similar) collaboration site, project admins, contact information, collaboration locations) • Linking Strategy (whether it is One Model Strategy, Multiple Model Strategy, Floor based linking, Nested linking) • Model Control Strategies (worksets, naming conventions for new worksets, copy/monitor, Coordination views, phasing) • LOD (Level Of Detail) Matrix • Pre-Construction Model Checklist • Clash Detection

4. PRISMARCH FRAMEWORK: VIRTUAL REALITY AIDED DESIGN BLENDING

The scope of this section is to extract the user and functional requirements of AEC experts with respect to VR systems that enhance the design procedure in a structured format. The outline of this section is as follows. The key user requirements are presented in Section 4.1. The notions that will be used in the project are described by the definition of proper taxonomies, constraints and rules that are presented in Section 4.2. The methodology to collect the requirements is presented in Section 4.3. Finally, the collected user and functional requirements are provided in Section 4.4.

4.1 Key User Requirements for the Construction of PrismArch Spaces

The PrismArch platform should help all disciplines to monitor the process of the digital assets' growth over the entire project lifecycle. The VR environment is a World Engine Space that should enable the disciplines to access the building design process in real-time. The time-based queries will allow disciplines to immersively review past and current project design processes. Suggestions could also be achieved with the AI guidance. The queries should also be able to achieve cost management.

Risk Management

From the discipline case studies and incident examples, it was evident that risks can be introduced at any stages of the project development including the construction stage and after project handover. Incidents often involve the actual physical site conditions that are uncovered after works begin on site, and these are often investigated and reported by project contractors. Project disciplines must be aware of these unexpected risks and be equipped to take action to solve these problems with minimum financial risk and full health and safety compliance.

Another substantial risk emerges after the construction stage, upon the handover of the information to the building operation managers. While construction/contractor warranty is typically valid for 12 years, the operation of the buildings and the design life of components (product warranties, etc.), can be left unmonitored or be ill-communicated causing delays and risk for the project. The AEC disciplines should aim to alleviate the risks associated with the maintenance and operational management by providing a well-organised and easily-accessible virtual record of the building and all of its parts.

Yet another major risk is introduced every time information is translated or exchanged between parties during the design stages. Whereas in some cases information is purposefully withheld, as when the tendering contractors have to run recalculations of the structural and MEP engineering models, in most cases the existing formative narratives and large volumes of data have to be absorbed by newly introduced parties. Information loss and misconceptions about the design narratives are associated with high levels of risk to the project outcome whenever information is passed to the next liable party. The abstract design space is perceived as having a certain level of indemnity from risk, but we must bring the awareness of the physical and economic risks resulting from ineffective or lossy information exchange into the setup of the PrismArch virtual environment. Coming to awareness of the risks through a holistic perspective of the project is the goal of PrismArch.

Client engagement and decision-making

All project disciplines must recognize the client's influence and authority throughout the development of the project - being the core driver of the project by making important and impactful decisions. These decisions often are made in workshops and during meetings using physical tools such as tracing paper, notepads, and usually involve discussions, all of which also take place outside of the actual discipline dependent production loop.

The project brief is one of the key deliverables to be developed by architects in collaboration with the clients, and the content of the initial brief is to be acknowledged by structural engineers, MEP engineers and all other disciplines. The project brief sets out guidance for developing the project, helps identify the disciplines that may be required for the project, and distributes essential tasks and responsibilities between them. This production loop also exists outside of discipline specific design spheres and not all disciplines might be onboarded at this stage. Each discipline has a different project start depending on when they are appointed and sign the contractual agreement. The PrismArch platform therefore should be flexible as to the nature of a project timeline and must meet the requirement of being able to change the project participants - add, revoke or change their access credentials.

Convergence of relevant reference information

Existing information from available online or offline resources such as the site history, local regulations, location of subterranean pipes and cables, ergonomic and architectural standards database, building code, cultural and material references used to create moodboards, are often stored separately, so it is not possible to overlay the information to obtain the full picture of the design constraints. Each discipline currently manages the information pertinent to their workflow, and is responsible for informing the others of any changes. However, we envision a system constructed similarly to the NVIDIA Omniverse, where all the available information can be seen and reviewed together. The PrismArch platform's Datasphere Space should act as a space of convergence for all relevant information that influences the outcome of the project. The information can be either stored completely in one place, or partitioned into a main server space with auxiliary (or proprietary) server spaces, depending on the type of information and the party it "belongs" to (the level of project involvement of the party), and the relation of this information to the deliverables. This information cannot not be unilaterally or immediately available to all PrismArch users, but accessed according to the users' project role and access privilege. For instance, it is necessary to withhold structural and MEP calculations from contractors, so that the contractor can verify their capability through doing their own calculations, and accept the liability for the construction. This is also used as another check for the engineers' calculations.

Discipline-specific work environments

It is clear that each discipline has its own responsibilities, expertise and knowledge. In most of the cases, each discipline has its internal production loop to develop internally approved options/solutions before sharing the ideas with other disciplines. These discipline-specific work environments are also valid for the PrismArch platform, in order to protect the authority and intellectual property of each of the respective disciplines. Additionally, from the software diagrams, it is evident that each discipline uses different market available software. Even when two disciplines use the same software or application, the way it is used varies from discipline to discipline. The PrismArch platform should not disturb the current cultural and traditional disciplinary workflow, but should help enhance and improve the self-contained work pipeline by blending all the disciplines' perspectives.

Record-keeping

Even when disciplinary tasks are approved both internally and externally during the design phase, not all the submitted materials are actually used during the construction stage. However, the PrismArch platform system should be aware that these hidden elements also have great potential to be a source of solutions for any unexpected risks or for future project opportunities. Additionally, the stringent regulatory guidelines that are being introduced in the UK as a result of the Hackett investigation indicate a shift toward the **Golden Thread principle**, whereby concise records of every decision will be required, as well as the criteria for the decision and any conditions that influenced it. The PrismArch platform should automatically generate a record of the project, including the full file version history, a record of internal and external meetings, decisions, approvals, submissions, and the detailed reason for any changes introduced along the way, either during design or construction. It would be useful to understand available quality assurance (QA) protocols and emerging regulations in order to formulate compliant formulae needed for the PrismArch platform to present those recordings.

General Note:

Virtual Reality for the PrismArch project means a mixed reality simulated world. Two-dimensional worlds are also a part of this (i.e. access from desktop monitors, tablets, phones etc.). In Table 4.1, we present the basic notions of the envisioned VR system.

Table 4.1: High level notions of the envisioned VR system.

PrismArch Spatial Construct
REALITY
Physical Reality
Virtual Reality
WORLD ENGINE / WORLD DATA
PRISMARCH WORLD SPACE + DATA (AEC Design and Collaboration Space)
PrismArch PROJECT Space + Data
Project disciplines' tool (Mindesk, third party software)
Project disciplines' space + data (i.e. client's space, ZHA space, AKT space, SWE space, contractual data, ZHA's IP, AKT's asset, SWE's asset)

The overall spatial construction of PrismArch is envisioned as depicted graphically in Figure 4.1 as an inverted prism. Specifically, in the bottom, the individual generators of information can be found such as designers of each discipline and as moving upwards, the generalization of the information in virtual space can be seen.

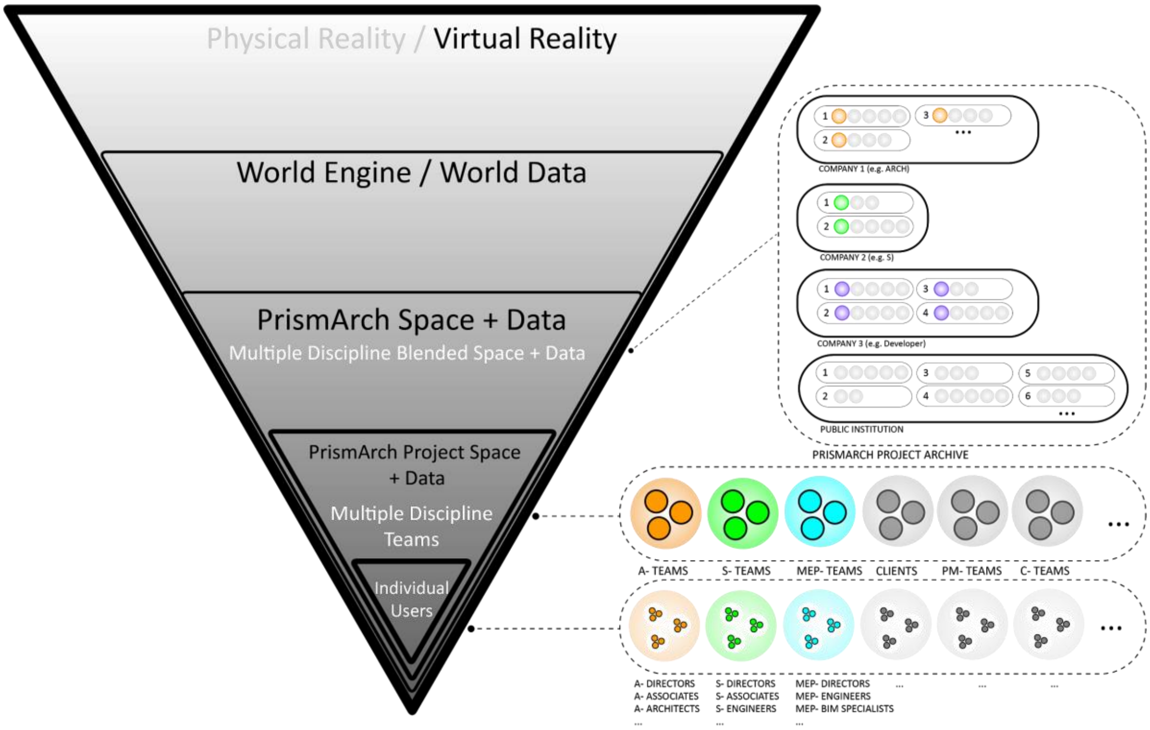


Figure 4.1: The spatial construct of PrismArch

The first layers of the prism are further analyzed in Figure 4.2 as they regard the basic disposition of the system data. Individual users (level 1) have to provide data into their discipline teams (level 2) that consists of several 3D assets and BIM or any other kind of metadata (negotiations, sketches etc).

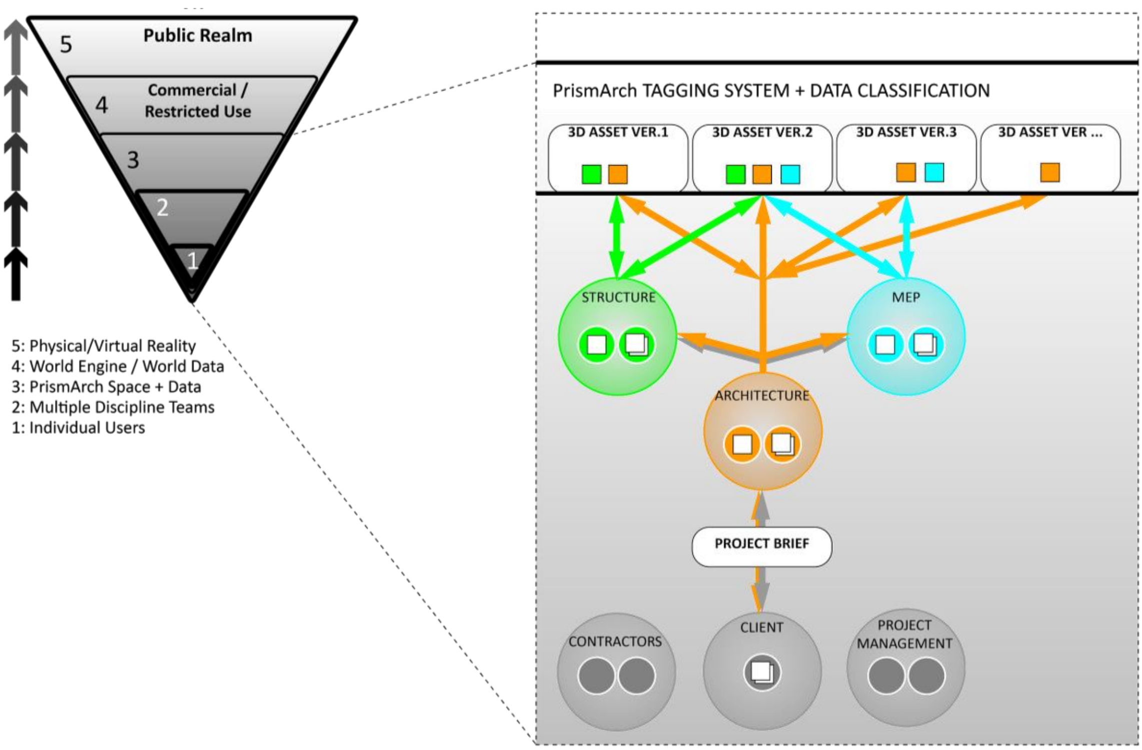


Figure 4.2: PrismArch data exploitation with tagging system

Secure data transfer and back-tracking history records of data are basic in the envisioned system as implied in Figure 4.3. Intellectual property should be kept throughout system usage, properties access rights should be provided by administrators when needed, and Clients of the project should be always informed about the status of IP.

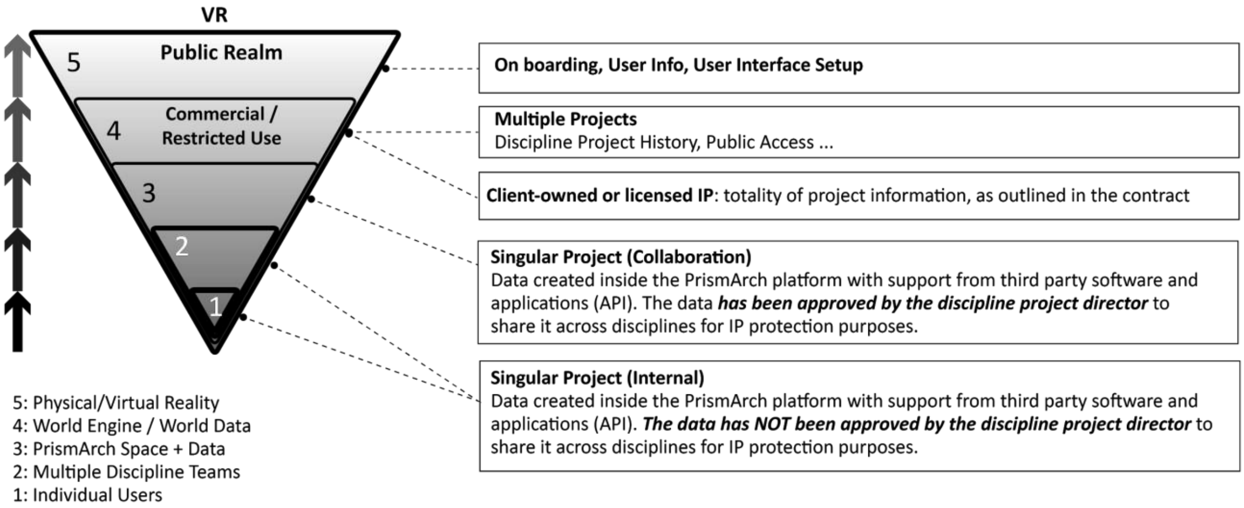


Figure 4.3: PrismArch Access Privileges and Data Protection

Interoperability with other software is essential as the platform should be easily extended with emerging 3D technologies. Figure 4.2. The system should have two separate kinds of interfaces, namely one for designers that will be experienced with the editing modes of the system, and a different one for clients that want to inspect design progress.

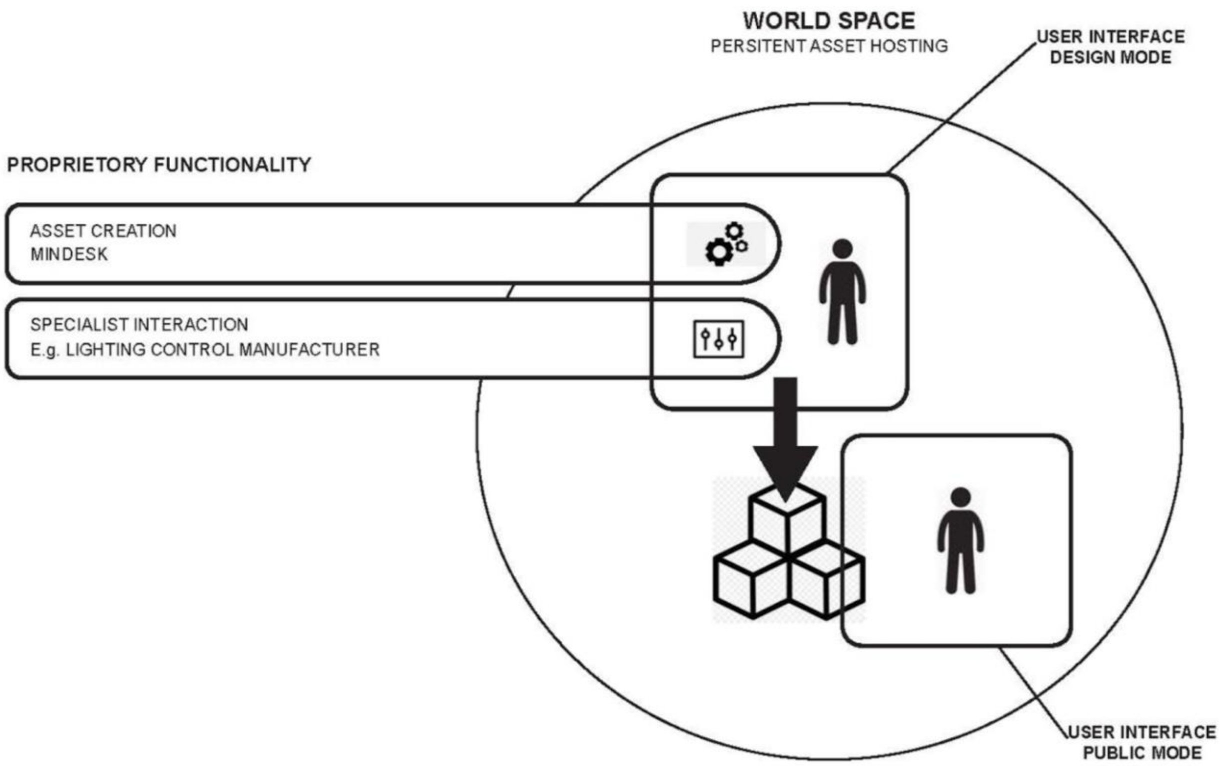


Figure 4.4. Interface design for asset creation is discipline specific and can be plugged in from other external software.

4.2 PrismArch Taxonomies, Constraints and Rules

According to the aforementioned discussion, the Taxonomies, Constraints and Rules are defined by the user, spatial and time dimensionality of the architectural project. Therefore, we have defined the following standardization to be followed throughout the project.

A. Taxonomies

World Type, Space Type, Data Type, Process Level, Level of Information, Discipline/User Type, Discipline/User Tools, Discipline/ User Data Type:

Each taxonomy has the following terms:

World Type: Physical Reality, Virtual Reality; World Engine; World Data

Space Type: Project Space, Discipline Space

Data Type: Project Data, Discipline Data

Process Level (UK/USA): Strategic Definition / Briefing, Mobilisation, Preparation of Brief / Feasibility Study, Concept Design/ Schematic Design, Spatial Coordination / Design Development, Technical Design / Construction Documentation, Construction, Post-Construction I / Handover and Close-out, Post-Construction II / Use

Level of Information: Design Reviews, Management, Diagrammatic, Documentation, Presentation, 2D/3D sketch, Orientation, Analysis, Aesthetic, Functional ...

Discipline/User Type:

- Customer: Private Clients, Developer Clients
- Admin: Project Administrator
- Management: Project Manager
- Architecture: Project Directors, Project Associates, Project Architects, Project Contributors, Local Architects
- Interior: Project Associates, Project Contributors
- Structure: Project Directors, Project Associates, Senior and Design Engineers, Senior and Junior BIM technicians
- MEP: Project Directors, Project Manager, Senior and Design Engineers, Senior and Junior BIM technicians
- Civil: Civil Engineers
- Landscape: Landscape Designer
- Consultants: Facade Consultants, Waterproofing Consultants, Fire Protection Consultants, Lighting Consultants
- Contractor : Main Contractor, Facade Contractor, Glazing Contractor, MEP Contractor
- Press: Senior Associate, Digital Media Manager
- Event Curator: Event Curator, Venue Owner
- Public Audience: Public Engagement

Discipline/User Tools:

- Immersive: GravitySketch, Medium, Mindesk, Twinmotion,
- Game Engines: Unreal Engine 4, Unity, Omniverse
- Specialist: IES Virtual Environment (IES VE), One Click LCA, Elmhurst Design SAP, Pyrosim, Pathfinder, Specialist AV Software, Reakt (AKT's in-house Interoperability platform), Project-specific C# and Python scripts, Plaxis 2D / 3D

3D: 3ds Max, Maya, Microstation, AutoCAD, Revit, Navisworks, MicroStation, BIM360, Rhinoceros 3D, Grasshopper, SketchUP, SolidWorks, Trimble ProDesign, DIALux, WinDEBUT, GASWorkS, SAP, Sofistik, Robot, FBeam, S-Concrete, TEDDS, RAPT, IDEAstatica

2D: Sweco Internal Software, Bluebeam Revu, Sticky Notes, MS OneNote, MS Planner, Microsoft Office, After Effects, Media Encoder, Indesign, Photoshop, Illustrator, Google Maps, Web Browser, PDF Xchange, Snipping Tool, Photos

Communication: Zoom, MS Teams, Skype, Outlook

System: Operating System, Graphics Card

Physical: Meetings, Reviews, Phone Calls, Physical Model, Hand Sketches, Hand Calculation

Discipline/ User Data Type:

Architecture:

- Contractual setup
- Local and global building regulations
- Site info (models, photos, point cloud data, weather, geographical data)
- Precedent projects (formal and program analysis, images, 3D models)
- Cultural and aesthetic references (concept research, images)
- Solar / Shading studies
- Materials and textures
- Construction method
- Computational tools and software (design process and results [e.g. grasshopper parameters to explore aesthetically-pleasing and energy-efficient facade design])
- Project brief (client's requirements)
- Program, Circulation, Zoning (private vs public), Project Area Calculations, Spatial Organisation
- Physical models and mockups
- 2D orthographics drawings (plans, sections, elevations)
- Hand sketches

Structure:

- Historical site information and database
- Local and global building regulations
- Safety and durability
- Structural performance (load, stress and strengths)
- Material performance and characteristics
- Beams, columns and foundations
- Building sustainability
- Architectural design, programme quality, adaptability, buildability
- Health and safety
- Test results
- Documentation

MEP:

- Building height ratio, environmental data
- Basement space planning

- Traffic and logistic planners
- Landscaping and public realm ventilation openings to spaces below ground
- Rainwater attenuation and storage
- Sub-slab drainage
- Riser and distribution zoning
- Low and zero carbon systems (LZC) integration
- 3D model / building information modelling (BIM)
- Construction programme and cost plan
- Electrical distribution
- Lighting requirement

B. Constraints:

Access Privilege

Individual/ User Data

- “Cannot proceed / Work in progress” (personal)
- “Can View” (within the same discipline space)
- “Can Comment” (within the same discipline space)
- “Can Edit” (within the same discipline space)
- “Can Share” (within the same discipline space)
- “Can Submit” (to external disciplines not to client)

Discipline Project Data (Team-based Information)

- “Cannot proceed / Work in progress” (only open to the same discipline members)
- “Can View” (within the same discipline space)
- “Can Comment” (within the same discipline space)
- “Can Edit” (within the same discipline space)
- “Can Share” (to external disciplines not to client)
- “Can Submit” (to client)

Data Authority / Ownership of Data

PrismArch based General IP

Data created within the experiential space by each author/user from any discipline

Discipline brand IP

Data loaded from the Physical Reality space, or modified data based on the loaded data.

Public IP

This is equivalent to putting information out into the internet - any information put out into the public realm must be ironclad, and filtered significantly to protect our immediate commercial interests.

Client Owned IP (proprietary)

Discipline-based IP and liability management (proprietary) - distinct specialization and distinct liability that is part of the overall skill-set needed to resolve the project

C. Rules

Licensing of Commercial IP - IP is owned by author / designer / manufacturer (ownership of design expertise and brand always stays with the design practice or author).

Project-related Information that is singular in its use, and is needed to resolve the project, is released by the respective authoring entity into the shared project space. This information is temporal, licenced to the client for a certain use, and is hosted inside the client's domain. There could be some exclusivity to this information (use limited to a certain market).

Public Realm and exclusivity: the project could, potentially, only be visible to a certain part of the public, dependent on royalties for distribution and rights.

Examples: "Project Contributors can not close their assigned tasks unless the Architectural Project Director approves them" or "Project Directors from all disciplines can not submit their production until getting approvals from all other Project Directors. Until this is done, the project cannot proceed to next process level/phase (however, all disciplines can go back to all submitted and approved project-related events (incidents) from the past" or "Client can visit and approve the discipline approved content inside VR" or "AI agent can not edit Structural design but can propose the correct structural loading criteria based on the applicable local structural regulations (e.g. hurricane zone wind loads)"

Remarks

On the transmission of discipline specific data into the PrismArch World Engine, there should be a data classification process. Each data element should have a representation of the author signature and timestamp, so that the data itself and the authors' intellectual properties are protected. The PrismArch platform sees this attached asset metadata as a label or a tag that works as the genetic information (DNA) of the data (Figure 4.5).

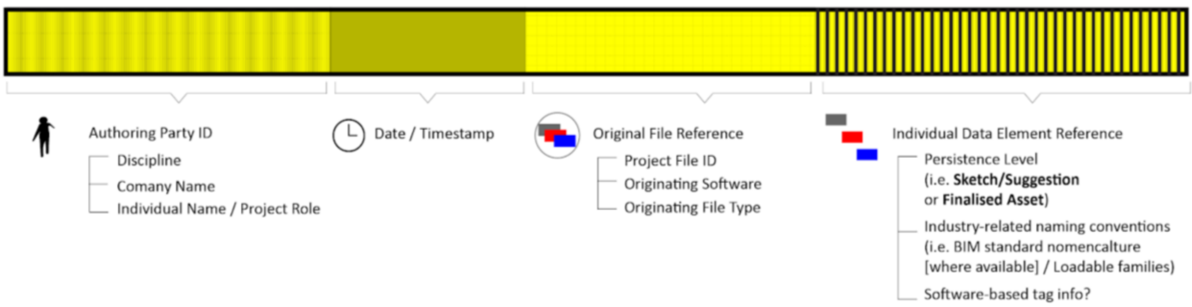


Figure 4.5: PrismArch asset DNA composition.

Data cannot exist inside PrismArch World Engine unless the asset has the genetic label/tag, thus and every asset that exists will have a unique label/tag that works as an identifier. Bringing data into the PrismArch World Space (AEC Design and Collaboration Space) requires an identification system that allows the system to track of the component, know its file origin, author, timestamp, version, and any other metadata relevant to the functioning of the PrismArch World Space as outlined in this document. Using the filtering tool proposed for the PrismArch Platform, disciplines should be able to access, search, and interact with the data.

Below shows the conversation between Architectural Project Director and Structural Project Director in regards to the proposed tagging system, recorded on 4th December 2020. It shows that time is an important aspect to manage architectural projects and data reviewed inside the virtual reality environment/World Engine space. Data resides in the Singular Database Space should be trackable via time or keyword-based query system. Such as quantitative, weight and cost data should be called with the query system, any risks should be highlighted with the assistance from AI.

Tagging system discussion - WP1 Workshop recording 03, 4th Dec. 2020

ZHA: "Tracking / tracing rule compliance. Tagging is a major issue - taking visual data that we can see in VR and turning it into a legal record - a real constituent of the project development - means that we have to have all this information attached to the component. Linked file aspect - communicating information OUT of the VR platform (into Maya, into Rhino, into other software)."

AKT II: "Time-based platform - allows AKTII to understand specific tagged parts' development throughout the stages of the project and how they impacted design choices or cost.", "Tracking an element to see how it was manipulated or removed in the course of the design - progression of a specific solution could be described in more detail", "Track level of definition of elements; assign useful parameters (quantities, weights, costs, etc)"

ZHA: "Could be useful to have a filtering opportunity - either by responsibility or by design discipline", "type approach, time-based, stage-based checklist would be required.", "Information logistics are not necessarily discipline-specific", "the linked file aspect: Information has to be transported OUT of the VR space back out to the model. This cannot / should not be done by a human. It would be helpful to automate this."

The diagram below (Figure 4.6) shows the varying levels of AI guidance that can be deployed. Low-level or elementary guidance deals exclusively with rule-based design criteria that pertains to each of the three disciplines - and is rooted in the discipline-specific libraries of codes and regulations that apply to that particular project (i.e. structural design parameters for tall buildings in the hurricane zone, as defined by building authority of Florida State in the United States).

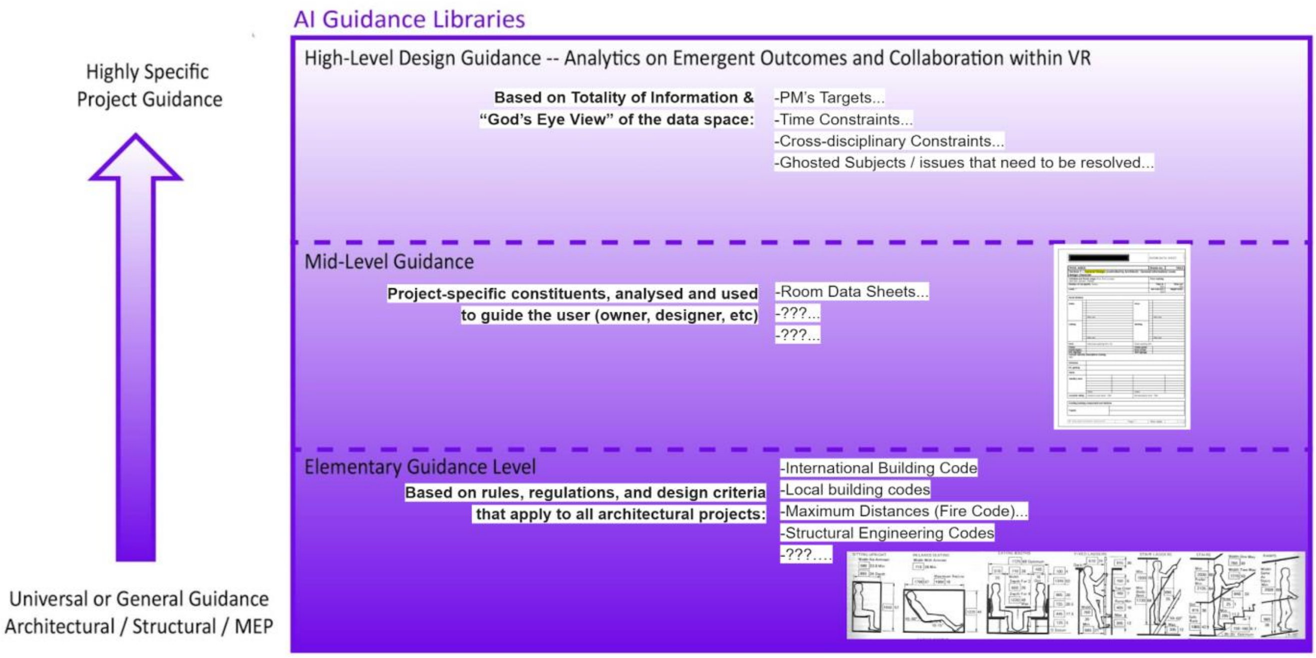


Figure 4.6: PrismArch AI guidance levels.

At the next level, we have guidance that involves the coordination of data between disciplines for a specific project. The room datasheets, for example, contain information about all the fixtures of a given building, room by room. These are painstaking and time-consuming, and are currently done manually by multiple disciplines. The auto-generation or intelligent handling of repetitive regulatory forms based on the encoded project data within PrismArch could offer great benefit to the entire project team.

This AI diagram is not only a drawing for types of AI, but also a roadmap. We cannot ask AI to help with project-specific co-authoring guidance until there exists an established inference toolkit for the generic, low-level data. At the top, High-Level design guidance could allow us to track and monitor the development of the project-based deliverables, actions, and interactions. This project-level guidance would evolve together with the PrismArch platform, and would monitor deadlines, track any issues or areas of the project being overlooked, and identify any such “blind spots”, raising any potential issues to awareness (e.g. critical data not received, or a completed structural calculation not reviewed / not approved for submission).

Below shows the conversation between Architectural Project Director, Structural Project Director, Cognitive Science Researcher and Associate Researcher, in regards to the implementation of Artificial Intelligence to the platform, recorded on 4th December 2020.

AI implementation discussion ---- WP1 Workshop recording 03, 4th Dec. 2020

ZHA: “Potential task is for AI to guide the users. The tasks are repetitive, so for each project there is Information logistics that are not discipline-specific. (AI could) Follow users and keep track of the inputs.” Not sure if we can define this in terms of rules, but something that could work would be an anomaly-detecting device, that could say, “you looked at every single plug, but have not checked this one”, “AI will be necessary to help us translate our outputs into the digital VR space. We don’t want the AI to work as a solution-provider directly, but rather as an assistant to the process, suggesting one possible route to go. We want the AI as a guide to the user.”, “Turning the day-to-day interactions into a record”

AKT II: “It would be interesting to explore the use of AI in the structural realm to highlight the risks of specific stages. In the house (Residential Villa Case Study example), we may realise that we need a structural solution for the building, but we have not yet received the building info.”

ETH Zurich: - “… this can be defined in terms of coded rules - something that adapts to the usual behaviour of the user: you have looked at every single plum, but not this one. This would be what a human practitioner would do. AI would adapt to how humans interact.”

Panagiotis CERTH: “we don’t want the AI to work as a solution-provider directly, but rather as an assistant to the process, suggesting one possible route to go.”

ZHA: “AI will be necessary to help us translate our outputs into the digital VR space”

AKT II: “If we laid down the system, and the concepts behind them, it will automatically grow. The more data you feed it / the more projects you realize, the more the assistant will guide you. For example: pile into sandy ground - you put the pile there in the beginning, but when you received the samples, it said there was sand there... (the AI could flag that there was a pile now going into sandy ground)”

4.3 Requirements methodology collection

The requirements from use case partners (ZHA, AKT, and SWECO) are provided in “Requirement Shells”. Each requirement shell has the format presented in Table 4.1.

Table 4.1: Prototype Requirement Shell

Requirement #: [Number]		Req Type: [User or Functional]	Use Case(s): [Residential or Commercial]
Source	[Who raised this requirement]		
Description (Unambiquity)	**[A one sentence statement of the intention of the requirement]**		
Features (Completeness)	[Describe the features of this requirement]		
Rationale	[A justification of the requirement]		
Fit Criterion (Verifiability)	[A measurement of the requirement such that it is possible to test if the solution matches the original requirement. How can we verify that this feature is working? Example: When I press a button, the size of the wall increases by 1 unit.]		
Supporting Materials	[Any reference material]		
User Satisfaction	Degree of stakeholder happiness if this requirement is successfully implemented (Scale from 1= uninterested to 5 = extremely pleased)	User Dissatisfaction	Measure of stakeholder unhappiness if this requirement is not part of the final product (Scale from 1 = hardly matters to 5 = extremely displeased)
ZHA			
AKT			
SWE			
Existing		To be developed	
Related Task		Responsible Partner	
Dependencies	[A list of other requirements that have some dependency on this one]		
Conflicts (Consistency)	[Is it in contradiction with other components or standards? Does the technology exist to implement this?]		
History	[Creation changes, deletion, etc.]		
Relevancy to the project	[Yes or No and why ?]		
Feasibility	[Yes or No and why ?] Mindesk: CERTH: UoM:		

4.4 Requirements collected

In this section we present a collection of requirements according to the needs of Architects, Structural Engineers, and MEP engineers. These requirements are summarized in Table 4.2 and are described in the rest of the section with the "Requirements Shell" methodology as it was presented in Section 4.3.

Table 4.2 - Collect requirements short description.

New	Type	Short Description
1	Multi-presence on-boarding system	Managing interactions inside a multi-presence immersive space
2	Tagging tool	Flexible data management system for tracking data inside PrismArch
3	Query tool	Allowing users to isolate relevant assets from the totality of project information
4	Dashboard tool	A one-stop reference for coordination purposes
5	Admin tool (Project Settings)	Managing the access privilege, create discipline-based defaults and settings, edit project schedule, and set tasks
6	Contact/Communication tool	Integration of present-day networkability and communication channels into the VR environment
7	Toggle Camera Perspective tool	Allowing user to view the project from several key perspectives repeatedly without having to travel to them each time
8	Toggle View Mode tool	Allowing different ways of viewing and reviewing 3D assets, each suitable for a distinct work activity
9	Multi selection tool	Allows for highlighting, grouping, isolating, showing/hiding objects
10	Speech to text / typing tool	Speed and efficiency of text inputs
11	Commenting and Mark-up tool	This is a helpful way to keep track of comments and quickly exchange ideas inside the virtual environment.
12	List maker tool	Organizational efficiency
13	White Board tool	whiteboard inside VR space, to be able to pin reference images for individual use, or to share during meetings
14	Clipping Plane tool	Provides ability to see and evaluate the cross-section of a 3D construction
15	Spatial Orientation tool	To assist the immersed users with wayfinding inside the project
16	Design Support and Evaluation tool	Assists with spatial planning and evaluation

<table>
<tr><th colspan="2">REQUIREMENT #: 1</th><th>REQ TYPE: FUNCTIONAL</th><th colspan="2">USE CASE(S): ALL</th></tr>
<tr><td>Source</td><td colspan="4">ZHA</td></tr>
<tr><td>Description (Unambiquity)</td><td colspan="4">Multi-presence on-boarding system</td></tr>
<tr><td>Features (Completeness)</td><td colspan="4">● Choosing to host a meeting or to become an attendee
● Attendees can become a presenter when assigned to this role by the host
● Inviting users to a virtual meeting space, presentation space, or a discipline work space (depending on the host's selection)
● Having human presence: user avatar, user name tag, voice, etc.</td></tr>
<tr><td>Rationale</td><td colspan="4">Needed for managing interactions inside a multi-presence immersive space</td></tr>
<tr><td>Fit Criterion (Verifiability)</td><td colspan="4">● Users can access the lobby space
● Host can create a meeting space and can access the meeting space
● Host can invite users to the meeting space
● Attendees can accept the invitation and join the meeting space
● Host can assign a presenter and Host can assign another host to take their place
● Attendees can leave, Host can quit the meeting
● User name tags are visible and facing towards other users with proper font size
● Users recognise and distinguish each presence and its discipline and role
● Users can join the session from different types of devices (i.e.) headsets, desktops, tablets, phones…
● Active project members can join sessions through both the multi user editor mode, and also through the packaged version, to have most flexibility
● Public users would most likely access sessions through the packaged version
● Test performance and speed, to understand the limitation in number of users</td></tr>
<tr><td>User Satisfaction</td><td>(Scale from 1= uninterested to 5 = extremely pleased)</td><td>User Dissatisfaction</td><td colspan="2">(Scale from 1 = hardly matters to 5 = extremely displeased)</td></tr>
<tr><td>ZHA</td><td>5</td><td></td><td colspan="2">5</td></tr>
<tr><td>AKT</td><td>5</td><td></td><td colspan="2">5</td></tr>
<tr><td>SWE</td><td>5</td><td></td><td colspan="2">5</td></tr>
<tr><td>Existing</td><td>Multi-user editing Unreal Engine</td><td>To be developed</td><td colspan="2">Custom functions for the Multi-user Unreal Engine interface</td></tr>
<tr><td>Related Task</td><td>T4.4</td><td>Responsible Partner</td><td colspan="2">CERTH</td></tr>
<tr><td>Dependencies</td><td colspan="4">All tools</td></tr>
<tr><td>Conflicts (Consistency)</td><td colspan="4">Currently the proposed technology does not conflict with any of the other requirements or components of the overall system.</td></tr>
<tr><td>History</td><td colspan="4">Creation changes, deletion, etc.</td></tr>
<tr><td>Relevancy to the project</td><td colspan="4">This requirement is relevant to the project and aligns with the description of the grant agreement.</td></tr>
<tr><td>Feasibility</td><td colspan="4">Multi-user capabilities are partially supported from the Unreal Engine editor as. multiple users can connect to the same editor scene (from their own instance of the unreal engine) and simultaneously perform edit actions. Also, there is multiplatform support, enabling users to connect from both a VR or desktop mode. Lobby creation and other multi-conferencing capabilities will be examined in T5.1.</td></tr>
</table>

REQUIREMENT #: 2	REQ TYPE: FUNCTIONAL	USE CASE(S): ALL
Source	ZHA, SWECO	
Description (Unambiquity)	**Tagging tool**	
Features (Completeness)	As soon as a new asset is introduced and recognised inside the PrismArch platform, the system assigns a persistent tag (Persistent Unique Asset [DNA] Code) to the asset. The asset tag list is stored in a singular database for all PrismArch virtual assets. The asset directory should be trackable, thus a clear definition of author is required (asset IP) ● All assets existing inside the PrismArch must have unique and identifiable serial numbers (automation of asset DNA creation) ● The tag storage location and the data classification can be customised both inside and outside of the VR environment in real-time ● The singular tag storage has a self-referencing system ● Data can be streamed inside VR using the tags and can be loaded asynchronously ● The tag system corresponds to version controls ● PrismArch users can add further information on top of the persistent asset metadata inside the PrismArch platform Example 1. The persistent asset data has a timestamp of when it is created with its authors' name, but the cost information is modifiable inside the PrismArch platform. Example 2. PrismArch users can select multiple assets inside the VR environment, create a group and assign a new tag to the selection. On creation of the new tag, the information is added to the singular tag list and users can access the information via a query tool. Side notes: GitHub and GitLab would be good system references. Key Chain data storage could be a potential solution to store and manage the Asset List safely and without single location weaknesses.	
Rationale	Flexible data management system for tracking data inside PrismArch	
Fit Criterion (Verifiability)	● On loading the asset, the system reads the asset metadata and it is sent and saved to the singular tag storage. ● When a user highlights an asset, the metadata is recognisable inside the VR environment. ● When metadata is recognised, users see an option to add information. The information input is seen in the VR environment and when users select 'Save' or 'Update', the input is added on top of the persistent asset metadata. ● When the original asset is updated, the only changed part is updated asynchronously ● Users will see the real-time metadata update inside the VR environment if users are in the environment. If not, the latest update will appear on the PrismArch dashboard. ● When changes are made, the current version creates a backup and users can call the version history by entering the tag values.	

Supporting Materials	GitHub and GitLab would be good system references.		
User Satisfaction	Scale from 1= uninterested to 5 = extremely pleased	User Dissatisfaction	Scale from 1 = hardly matters to 5 = extremely displeased
ZHA	5		5
AKT	5		5
SWE	5		5
Existing	Unreal Engine Tags System / File Management	To be developed	Custom VR tags in Unreal Engine editor and Custom File Exporters
Related Task	T4.4	Responsible Partner	CERTH, MINDESK
Dependencies	Unreal Engine, Rhino tags data, Revit tags data		
Conflicts (Consistency)	No particular conflicts can be identified for this requirement.		
History	Creation changes, deletion, etc.		
Relevancy to the project	This requirement is relevant with the scope of the project.		
Feasibility	The tagging function can be supported from current game engines' architectures through pre-existing tagging and labeling native mechanisms. The system will allow designers to customize the available tags and labels as well as provide custom interface widgets for easily setting labels to selected objects or groups of objects. Moreover, through communication with the singular database (API calls) the available tags would be displayed in the interface.		

REQUIREMENT #: 3	REQ TYPE: FUNCTIONAL	USE CASE(S): ALL
Source	ZHA, SWECO, AKTII	
Description (Unambiguity)	**Query tool**	
Features (Completeness)	The PrismArch platform helps all disciplines monitor the process of digital assets' growth over the entire project life and enables the disciplines to access the building process in real-time. The time-based query allows disciplines to immersively review past and current project design processes, and future detection and suggestions could also be archived with the AI guidance. The query should be closely linked to cost management. **The query source of information can be entered by:** 1. Searching a keyword via text (keyboard or speech-to-text input)	

2. Using a time-based user interface to select a specific date
3. Using an intelligent time-based user interface to select project events and project phases
4. Interacting with 3D assets by highlighting objects

Functionality example: users filter information by #project phase #scopes #clash controls #project member contact #asset names #time stamps #asset types #Customised group names #incident name #IBC codes etc…

There are two-time aspects in the platform:

1. Project evolution sequence
Shows history of versioning as users change the time slider values

2. Construction sequence
Shows simulation of future events, such as the building process, following the construction schedule

- Game-time and Physical-time should be linked to review, simulate and animate the user queried content. Game environment matches the geo and solar locations (plus climate)
- International standards should be the default

Query tool design example

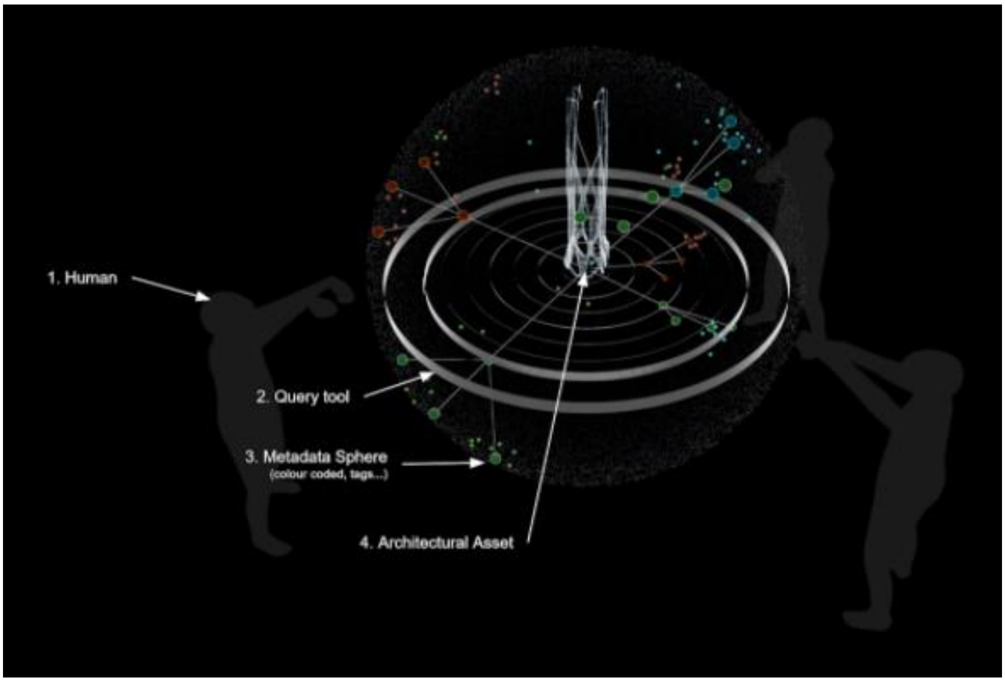
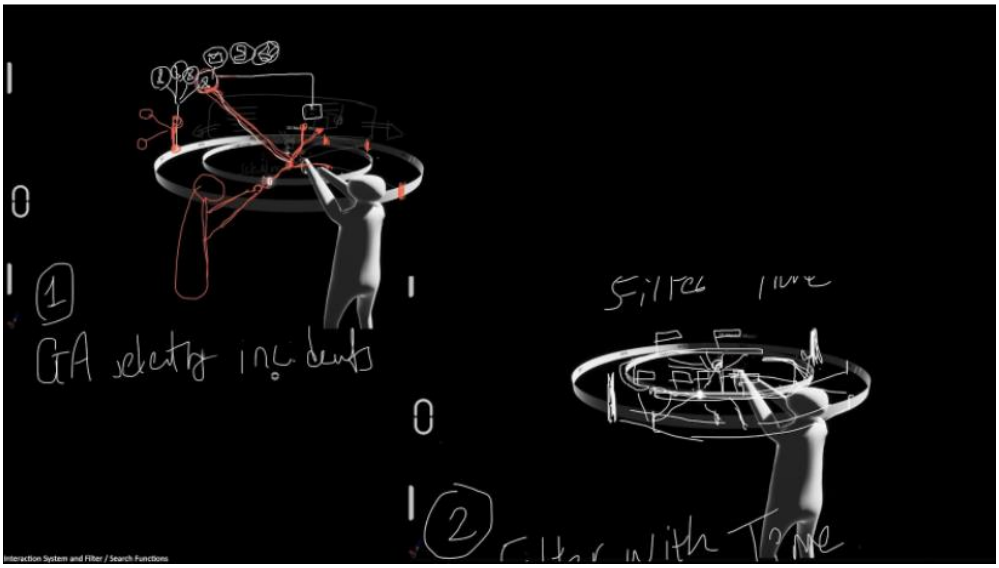


Figure 4.4.1: ZH Sketch Legend: 1. Human; **2. Query tool;** 3. Metadata ; 4. Architectural Asset

Progressive project 3D assets are loaded at the center of a wheel-like time-based user interface, which works as a collaborative query tool. The query tool functions as a connection between human presence and asset metadata. Queried data is visualised as populated and distributed spheres (or a simple forms) with treelike structure and patterns. The visualised data should have colour coding to distinguish the authors.

	 Figure 4.4.2, sketch by ZHVR, 5 Feb 2021 Furthermore, in the mockup of figure 4.4.2, the slider is divided by architectural project phases. Users can scroll the wheel horizontally to reach the project phase they would like to look into. Users can scale up the selected phase and as the scale ratio increases the scale of the information resolution increases (as you users scale up one phase, more information dedicated to the phase appears). The query tool can also be linked to the Toggle View Mode Tool (e.g. viewing a cut-away perspective of the selected design options).		
Rationale	This function would allow users to isolate relevant assets from the totality of project information		
Fit Criterion (Verifiability)	● Search input is called correctly from the singular tag storedge ● The correct search outputs are uploaded at the centre ● Objects are selectable and highlighted (disciplines have different colour coding) ● Wheel is scrollable and the segments are scalable ● Data visualisation is updated in real-time via user input (searching via text, voice or direct selection) ● The slider can be scrolled horizontally correctly - suggestion: having physics and audio would be nice for the scrolling movement, it adds more haptic and tactile experiential aspects		
Supporting Materials	Mockups provided by ZHA		
User Satisfaction	Scale from 1= uninterested to 5 = extremely pleased	User Dissatisfaction	Scale from 1 = hardly matters to 5 = extremely displeased
ZHA	5		5
AKT	5		4
SWE	5		4
Existing	-	To be developed	Unreal Engine VR interface with custom Query / Filtering tools

Related Task	T4.4, T4.2	Responsible Partner	CERTH, MINDESK
Dependencies	A list of other requirements that have some dependency on this one		
Conflicts (Consistency)	No particular conflicts can be identified for this requirement.		
History	Creation changes, deletion, etc.		
Relevancy to the project	This task is relevant with the description of work.		
Feasibility	In order to ensure the technical feasibility of this requirement, we will need to use the available Unreal Engine UI development API, so to create a custom interface to facilitate the aforementioned query and filter actions. Access to BIM information directly into the VR interface can be implemented through centralized backend services.		

Requirement #: 4	Req Type: Functional	Use Case(s): All
Source	**ZHA, SWECO, AKTII**	
Description (Unambiquity)	**Dashboard tool**	
Features (Completeness)	Time scenarios, history tracking of past events, and the ability to project into the future. ● The tool functions similarly to flight dashboards or trading monitors. ● **Dashboard is the place where all users can monitor overall progress of the project** ● The tool functions as a calendar for all disciplines, and it should reflect the physical time (the dashboard can be filtered by project stages, month, week) ● Having a physical time (clock) on the dashboard would be helpful. The time shown should be indicating the physical, local time of the user (and indicate if he/she leaves the physical time for simulation purposes; speeding up or revisiting time, etc.) ● All users have access to the overall project schedule inside the VR space (provided by the Project Manager) <u>Example: All disciplines see each other's work status (who is working on which tasks, the status of: approved, not approved, delayed, canceled, in progress, submitted..)</u> If the project has no scheduled data yet and if the BIM model was not integrated at the project start point, the dashboard should still be activated by designers producing or modifying assets inside the platform. The project start date on the calendar should be the first date that the first asset information was available in the PrismArch singular tag storage. If BIM data is to be implemented on top, the project start date will still be the first date of the first asset that is created outside the BIM system. The last date will be the data created within the BIM system.	

Rationale	A one-stop reference for coordination purposes		
Fit Criterion (Verifiability)	● Dashboard can be seen from the individual perspective of each of the users As with the general user UI, the visibility and the composition of the dashboard should be customizable. (This is shared information but the dashboard itself can be hidden or shown at the personal user level settings. If users are in a meeting space, the host should have the admin right to show or hide the project dashboard) ● When users change the work status, it should be immediately reflected on the dashboard		
Supporting Materials	Something similar to flight dashboards or trading monitors		
User Satisfaction	Scale from 1= uninterested to 5 = extremely pleased	User Dissatisfaction	Scale from 1 = hardly matters to 5 = extremely displeased)
ZHA	5		5
AKT	5		5
SWE	5		5
Existing	Revit Timeline	To be developed	Unreal Engine Timeline dashboard interface
Related Task	T4.4, T4.2	Responsible Partner	CERTH, UOM
Dependencies	A list of other requirements that have some dependency on this one		
Conflicts (Consistency)	Currently the proposed requirement does not create any conflicts with any of the other requirements or components of the system.		
History	Creation changes, deletion, etc.		
Relevancy to the project	This requirement is relevant with the description of work and expertise of consortium partners.		
Feasibility	In order for this requirement to be considered feasible two components need to be developed. First of all, a custom VR interface is required that will be developed using the Unreal engine that will display user queries. Moreover, the BIM integration and access to the history dashboard, will be developed through custom based backend online services.		

REQUIREMENT #: 5	REQ TYPE: FUNCTIONAL	USE CASE(S): ALL
Source	ZHA, AKTII	
Description (Unambiguity)	**Admin tool**	

Features (Completeness)	● Admin tool controls the access privilege of the project team members, and provides a way of changing general settings of the platform (e.g. onboarding and registration, managing accounts, etc.) ● Admins can set the totality of the project theme and discipline-based default settings, including everything from view mode defaults (e.g. white/dark UI modes) to the documentation style: font, text size, and colours for the master documentation template of the project. Individual users can then customise their own work space as needed. ● The Project Manager and Project Directors can assign admin rights to other project members using the tool ● The Project Manager and Project Directors can distribute and assign tasks across disciplines. Assigned users can approve/leave further comments to the assigned tasks and PM and PD can review the response. ● All users have access to the project schedule that is created and edited using the Admin tool (can be reviewed with the dashboard) ● **Each discipline has directors to approve the distributed tasks (PD has the admin role in default settings) and the discipline team structure should be directly reflected to the initial admin settings**		
Rationale	A way to manage the access privilege, create discipline-based defaults and settings, edit project schedule, and set tasks		
Fit Criterion (Verifiability)	● Admins see the list of logged in/out users ● Admins assign and approve access privilege for certain data ● Users without access privilege contact the admins first to receive an access approval ● This communication should spontaneously happen while users are inside the PrismArch platform ● Accessing the general project schedule from the dashboard tool		
Supporting Materials	Similar to "Project Settings" that many software has		
User Satisfaction	Scale from 1= uninterested to 5 = extremely pleased	User Dissatisfaction	Scale from 1 = hardly matters to 5 = extremely displeased
ZHA	5		5
AKT	5		4
SWE	5		4
Existing	Revit Server Administrator	To be developed	Unreal Engine VR admin tools
Related Task	T4.4	Responsible Partner	CERTH, MINDESK
Dependencies	Contact / Communication tool, User Interface customization, access privileges, contractual setup		
Conflicts (Consistency)	No merging conflicts can be identified regarding the other listed requirements		

History	Creation changes, deletion, etc.
Relevancy to the project	This requirement can be considered relevant with the initial scope. However, it was not promised in the grant agreement and since there is no available partner in the consortium with relevant experience, we will rely on pre-existing technologies.
Feasibility	Since this is a challenging requirement to be developed from scratch, we would rely on the pre-existing feature of multi-user interfaces that Unreal Engine offers. Based on the role of the user (e.g admin) the interface would update accordingly. For the development of such a requirement a backend centralized service needs to be used that will act as the middle point between BIM and Unreal Engine so as to correctly visualize and support user rights and accessibilities based on predefined privileges. Using the email distribution mechanism from Requirement #2, users can assign and distribute tasks to specific members based on their email address. However administrate rights such as approving a task/project or replies to existing tasks scale with the complexity of the project. Therefore, in order to have a technically feasible requirement a backend service is needed to handle this administrative communication.

REQUIREMENT #: 6	REQ TYPE: NON-/FUNCTIONAL	USE CASE(S):
Source	ZHA	
Description (Unambiquity)	**Contact and communication tools** **(including text, voice and video calls from iphone, ipad, desktop and/or VR)**	
Features (Completeness)	● Users can connect to the existing communication tools from the PrismArch platform via API (one or multiple choices from tools such as Outlook, Gmail, Slack, Whatsapp, Skype, Zoom, etc) ● PrismArch contact list/phone book would be helpful ● Users can ping other users from the VR environment. **Text based and voice based chats** would be helpful ● PrismArch users should be able to communicate across media types including tablets, phone, desktop and headsets ● **Speech to text feature would be helpful**	
Rationale	Integration of present-day networkability and communication channels into the VR environment	
Fit Criterion (Verifiability)	● Contact list is shared across the platform users ● Users can ask the admins to add new contacts ● Check if API works with one or multiple applications in the list above (see *Features*) ● Users can ping each other while inside the VR environment ● Check that voice chat and text based chat both work	
Supporting Materials	Zoom, Skype, and Outlook can be used as reference tools	

User Satisfaction	Scale from 1= uninterested to 5 = extremely pleased	User Dissatisfaction	Scale from 1 = hardly matters to 5 = extremely displeased
ZHA	5		5
AKT	5		5
SWE	5		5
Existing	Email Plugin	To be developed	Custom functions for the Email Plugin Interface
Related Task	-	Responsible Partner	CERTH, MINDESK
Dependencies	Virtual keyboard, Speech to text, Admin tool, API		
Conflicts (Consistency)	Integration with modern social media platforms directly from the Unreal engine, may be problematic, since not all providers can supply an API for their platform. However, the mail feature can be supported without any technical ramifications.		
History	Creation changes, deletion, etc.		
Relevancy to the project	It is relevant but not promised in the Grant Agreement. Therefore, some open-source tools could be exploited and tested if they could operate efficiently.		
Feasibility	The feature of sending mails/messages directly from the UE4 interface can be supported with already existing technologies. However, obtaining a list of contacts directly into the interface of the game engine, would require a backend service that could load and display the available email addresses. This could be facilitated with either an offline file reader with all the required email addresses or an online API that will provide the required information once the users have authenticated themselves (email plugin, unreal engine marketplace).		

REQUIREMENT #:7	REQ TYPE: USER REQUIREMENT	USE CASE(S): ALL
Source	ZHA	
Description (Unambiquity)	**Toggle Camera Perspective Tool**	
Features (Completeness)	● User camera perspective shortcuts for reviewing the loaded 3D assets from fixed points of view: as default, TOP, SIDE and PERSPECTIVE. ● Users can also add a new camera perspective. The saved camera transforms should appear in a user-customised interface ● In the VR environment, the camera perspective is the first-person view/VR camera. Users can rotate instead of the 3D assets having a local rotation (humans rotate the heads to look objects from different angles) ● The cameras can make a snapshot and users can assign a tag to save the images **Side notes:** These functions are generic in desktop / flat screen-based 3D modelling	

	software such as Rhino, Maya and 3DsMax, however, not very common in the existing virtual reality modelling tools.		
Rationale	Allows user to view the project from several key perspectives repeatedly without having to travel to them each time		
Fit Criterion (Verifiability)	● Users can save the current camera transforms and use them later ● Users can shift their perspectives and the PrismArch platform must suggest a way to teleport the user without motion sickness (i.e.) longer time of blinking / black screen on transition, users grab the environment to move around…		
Supporting Materials	Rhino3D, Maya, 3Ds Max; See also NVIDIAHolodeck [NVidia Holodeck]		
User Satisfaction	Scale from 1= uninterested to 5 = extremely pleased	User Dissatisfaction	Scale from 1 = hardly matters to 5 = extremely displeased
ZHA	5		5
AKT	5		5
SWE	5		5
Existing	Mindesk plugin in Revit	To be developed	Extend functionality in Unreal
Related Task	T4.2	Responsible Partner	CERTH, MINDESK
Dependencies	Tracking paper tool, User Interface		
Conflicts (Consistency)	No particular conflicts with other requirements seem to arise with the development of this requirement. Careful user testing is required for this tool to avoid motion sickness.		
History	Creation changes, deletion, etc.		
Relevancy to the project	Yes, relevant to the project and promised in T4.2		
Feasibility	The feature of toggle the view from the Unreal Engine interface can be supported with already existing technologies (UE4 plugin: MultiViews4UE4). There are the respective buttons which the user can toggle the view by pressing them. However, in a Virtual Reality environment, it will be more useful the creation of a tool which could toggle viewports with a specific button.		

REQUIREMENT #: 8	REQ TYPE: FUNCTIONAL	USE CASE(S): ALL
Source	ZHA	
Description (Unambiquity)	**Toggle view mode tool**	

<table>
<tr><td>Features (Completeness)</td><td colspan="3">Users can review the loaded 3D model with different render modes.

<u>Render modes:</u> white clay mode (Default); Colour coded mode (tagged groups shown in different colours); photo-realistic mode; wireframe mode; xray / ghosted mode; technical mode; simulation mode (point cloud and scan data); Raytracing on/off

Users can save the scene/level contents and load the level contents and materials when they need them. The saved and custom view modes can be called via the tagging and query tools

<u>User specific:</u> This content is developed by disciplines using the PrismArch platform with their preferable third-party software and applications. The toggle view mode tool helps to distinguish the parties’ own proprietary data or assets from the multidisciplinary context that they are not authorised to manipulate.

- animations
user paths, ergonomic animations, construction sequences, crowd simulation
- customisable work environment
view mode selection, background colours, studio lighting etc
- presentation
highly customisable branded mode with custom annotations and descriptions, scaling the model / miniature model mode</td></tr>
<tr><td>Rationale</td><td colspan="3">Allows different ways of viewing and reviewing 3D assets, each suitable for a distinct work activity</td></tr>
<tr><td>Fit Criterion (Verifiability)</td><td colspan="3">● Tags save the correct array of material and asset data.
● When tags are called the correct materials are assigned to the correct assets
● Turn on and off some features if the view mode introduces performance issues
● The colour pallette for the color coded view mode can be called from the admin default settings but users should also have freedom to customise it from the scene directly
● Presentation mode does not always need to be in photo realistic modes. Users should be able to make their own aesthetics inside Unreal Engine or using other software applications and run the content inside the platform.</td></tr>
<tr><td>Supporting Materials</td><td colspan="3">See how design software such as Rhino change their rendering mode</td></tr>
<tr><td>User Satisfaction</td><td>Scale from 1= uninterested to 5 = extremely pleased</td><td>User Dissatisfaction</td><td>Scale from 1 = hardly matters to 5 = extremely displeased</td></tr>
<tr><td>ZHA</td><td>5</td><td></td><td>5</td></tr>
<tr><td>AKT</td><td>5</td><td></td><td>5</td></tr>
<tr><td>SWE</td><td>5</td><td></td><td>5</td></tr>
<tr><td>Existing</td><td>Unreal engine rendering modes</td><td>To be developed</td><td>VR Supported rendering modes</td></tr>
<tr><td>Related Task</td><td>T4.4</td><td>Responsible Partner</td><td>CERTH</td></tr>
</table>

Dependencies	Tagging system, User Interface, Admin Settings
Conflicts (Consistency)	This requirement does not conflict with any other of the listed function requirements.
History	Creation changes, deletion, etc.
Relevancy to the project	This requirement can be considered as relevant to the project and close to the initial scope of the grant agreement.
Feasibility	Although the default editor in Unreal Engine, already supports a wide variety of rendering modes such as wireframe, unlit or shaded render mode, we will try to further extend all those capabilities to a VR interface. A set of widgets will allow users to easily switch to a different rendering mode. Moreover, if specific tags are specified to the loaded 3D models, a custom parser could recognize and automatically switch to the appropriate rendering mode. Therefore, the aforementioned requirement can be considered as feasible.

REQUIREMENT #: 9	REQ TYPE: FUNCTIONAL		USE CASE(S): ALL
Source	ZHA		
Description (Unambiquity)	**Multi selection tool**		
Features (Completeness)	● All assets should be highlightable and the highlighting colours should follow the colour palette set inside the Admin setting. ● Allows highlighting, locking, grouping, ungrouping, isolating, inverted, showing and hiding user selections ● Box selection method would also be helpful ● Users can assign and save tags for single or multiple selected objects for future reviews ● The name of last grouped and tagged assets can be found in the history tab inside a personal UI (local version control)		
Rationale	Allows for grouping objects		
Fit Criterion (Verifiability)	● a single object or multiple objects are selectable or highlightable via the Unreal Engine custom-depth/post process, etc.) ● The highlighting colours are discipline specific ● Multiple selected objects can be grouped, ungrouped, inverted, shown and hidden		
Supporting Materials	See for the similar actions inside Rhino design software		
User Satisfaction	Scale from 1= uninterested to 5 = extremely pleased	User Dissatisfaction	Scale from 1 = hardly matters to 5 = extremely displeased
ZHA	5		5

AKT	4		4
SWE	5		5
Existing	Level Design Assistant UE4 plugin	To be developed	Extend functionality in Unreal
Related Task	T4.2	Responsible Partner	CERTH, MINDESK
Dependencies	Selecting, grabbing, tagging tool, annotation tool, admin tool		
Conflicts (Consistency)	No particular conflicts with other requirements seem to arise with the development of this requirement.		
History	Creation changes, deletion, etc.		
Relevancy to the project	It is relevant.		
Feasibility	This function can be considered as feasible from a development perspective in Unreal Engine. An available example approach could be the creation of an editor tool that can select assets of a type or organize the selected assets in a desired folder. Users could call those folders, on any phase of the design, to edit them or toggle their visibility. The already existing UE4 plugin named as Level Design Assistant can be exploited.		

REQUIREMENT #: 10	REQ TYPE: USER		USE CASE(S): ALL
Source	ZHA		
Description (Unambiquity)	**Speech to text tool**		
Features (Completeness)	• Avoiding manual text input • Calling functions inside the virtual reality environment and **auto-correct and micro gesture features** would be helpful • Virtual keyboard might be needed as a backup plan		
Rationale	Speed and efficiency of text inputs		
Fit Criterion (Verifiability)	Voice is detected. if the user input is correctly inserted and translated into text. If the voice-entered texts are printed and visible in the widgets or in the scenes.		
Supporting Materials	See [Mozilla Common Voice], [sphinx-ue4]		
User Satisfaction	Scale from 1= uninterested to 5 = extremely pleased)	User Dissatisfaction	Scale from 1 = hardly matters to 5 = extremely displeased
ZHA	5		5
AKT	5		5
SWE	5		2

Existing	Speech to text libraries in Unreal Engine	To be developed	Unreal Engine interface with Speech to text tools
Related Task	T4.4	Responsible Partner	CERTH
Dependencies	Speech to text open source tools. Gesture recognition tools.		
Conflicts (Consistency)	No conflicts seem to arise from the development of this requirement		
History	Creation changes, deletion, etc.		
Relevancy to the project	It is relevant but speech technology is not covered by partners expertise nor promised in the Grant Agreement. However, gestures recognition is promised in T4.4.		
Feasibility	Speech to text can be considered as feasible from a development perspective in Unreal Engine (UE). In particular two approaches are available. First of all, an open source, UE plugin (sphinx-ue4) can be employed for speech recognition of simple sentences and commands. However, since an offline solution may not be sufficient enough to support a wide variety of languages and phrases, another backup plan would be to use speech recognition apis from cloud providers such as the Mozilla Voice platform. Such a solution would yield very accurate results with the cost of a pay per use policy. As regards gesture recognition, the Windows Mixed Reality SDK for Unreal can be exploited [Windows Mixed Reality Unreal Gesture Recognition].		

REQUIREMENT #: 11	REQ TYPE: FUNCTIONAL	USE CASE(S): ALL
Source	ZHA	
Description (Unambiquity)	Commenting + Mark-up tool	
Features (Completeness)	• *Toggle Camera Perspective* tool to add comments and mark-ups from a fixed viewpoint • Auto-location tool and default markup shapes would be helpful • *Speech to Text* tool or keyboard base typing to add and reply to discipline comments • Multi-selection tool and its box selection feature to add comments efficiency Side Note: This is not part of official or dimension drawings. This tool will be used for evaluation purposes only. Please refer to Design Evaluation tool for annotating features	
Rationale	This is a helpful way to keep track of comments and quickly exchange ideas inside the virtual environment.	
Fit Criterion (Verifiability)	• Markups and comments are attached to the object content • The spawned markups and comments are automatically resized according to the user distance • Users can show and hide the comments • Comments are trackable by the query tool Example: SWE added a comment on 2 March 2021 for the technical design phase. As	

	soon as the comments are added, it should reflect to the dashboard immediately. ZHA can find the comments by highlighting the commented asset or by searching the date or by searching from the time-base query tool. ZHA also can go to the dashboard and filter the monthly calendar to find the related incidents.		
Supporting Materials	-		
User Satisfaction	Scale from 1= uninterested to 5 = extremely pleased	User Dissatisfaction	Scale from 1 = hardly matters to 5 = extremely displeased
ZHA	5		5
AKT	5		5
SWE	5		5
Existing	Level Design Assistant UE4 plugin	To be developed	Extend functionality in Unreal
Related Task	T4.2	Responsible Partner	CERTH
Dependencies	Tagging and Query tools, Toggle Camera Perspective tool, Toggle View Mode, Speech to Text		
Conflicts (Consistency)	No particular conflicts with other requirements seem to arise with the development of this requirement.		
History	Creation changes, deletion, etc.		
Relevancy to the project	It is relevant.		
Feasibility	This tool can be considered as feasible from a development perspective in Unreal Engine. A tool that allows the users to author comments and attach them on a desired asset can be created. The tool can have a title line and a comment box to make it easier to read and organize. The ability to author those comments via Speech to Text tool could be explored and adapted to this custom tool. Already existing UE4 plugins: Level Design Assistant.		

REQUIREMENT #: 12	REQ TYPE: FUNCTIONAL	USE CASE(S): ALL
Source	ZHA	
Description (Unambiquity)	**List maker tool**	

Features (Completeness)	● "To do" list makers for all disciplines ● Project Directors and Managers can use the tools to list and distribute project tasks ● Architects and engineers can use the tools to manage their tasks ● The list has a tick box for each row and users can assign status of: work in progress, on hold, completed and approved/submitted ● The list and its items can be tagged at a personal level, however, in order for the users to share the status of the list items, they need to push the status to the dashboard and the query level. Users can then set the visibility of the tag. ● The disciplines gets notification when tasks are assigned		
Rationale	Organizational efficiency		
Fit Criterion (Verifiability)	● The listing columns and rows are customisable ● Admin default colour palette should be reflected in the list ● Tick box can be ticked or unticked ● 'Push status' button is required to set status visibility privilege		
Supporting Materials	NODA can be used as a reference: https://youtu.be/lICzYarsK8I		
User Satisfaction	Scale from 1= uninterested to 5 = extremely pleased)	User Dissatisfaction	Scale from 1 = hardly matters to 5 = extremely displeased
ZHA	5		5
AKT	5		4
SWE	5		3
Existing	-	To be developed	Custom Editor tool to authoring a to-do list that has the ability to send to other users via email
Related Task	T4.2	Responsible Partner	CERTH
Dependencies	Tagging and query tools, Speech to text/Keyboard tool, Admin tool		
Conflicts (Consistency)	No particular conflicts with other requirements seem to arise with the development of this requirement.		
History	Creation changes, deletion, etc.		
Relevancy to the project	It is relevant but it adds significant burden to the development as it is the description of an application (e.g. NODA) that should be done within VR.		
Feasibility	This tool can be considered as feasible from a development perspective in Unreal Engine. First of all, the to-do list inside the virtual reality environment can be created via a custom editor widget. Users will author the tasks that will include inside of the list. Then this list can be sent to other users by email through already existing Unreal Engine plugins that support email communication as it is aforementioned in Requirement #:2.		

REQUIREMENT #: 13	REQ TYPE: FUNCTIONAL	USE CASE(S): ALL
Source	ZHA	
Description (Unambiquity)	**White board tool**	
Features (Completeness)	● For Laying out digital references ● The reference board can be scalable and each image can be annotated ● Connecting to the web browser to drag and drop images Example 1. ZHA would like to review cultural references images and hand sketches; structural engineers would like to review geo-tagged images that are marching the site model next to structural diagrams; and MEP engineers would like to review the photos of the pipe alignment in the existing building or a floor plan. ● Users can type and make notes on top of the images using the commenting and mark-up tools ● Users can change the opacity of the white board and the whiteboard also functions as a tracing paper tool. This might have multiple layers to allow users to sketch on top of the references or over the 3D model (with assistance of the Toggle Camera Perspective tool). Users can add tags on each layer. Example 2. AKT is reviewing project site photos using the white board tool. The first layer has site photos, the second layer has a hand sketch of the structural principle with some hand calculations. A design engineer takes a snapshot using the Toggle Camera Perspective tool and places the image on the second layer. The top layer has another set of mark-ups. The engineer saves the output with tags; #hand sketch, #reference image, #snapshots. The engineer can see the history of hand sketches made in the last few weeks using the query tool and discusses the options with the Project Director. ● Users can draw lines inside the VR environment - auto correction would be helpful ● The drawn line thickness can be user customisable and (this can be transformed with control points - but this is not a top priority)	
Rationale	A whiteboard inside VR space, to be able to pin reference images for individual use, or to share during meetings	
Fit Criterion (Verifiability)	● Users can connect to the web browser from the virtual reality environment ● White board plane is scalable and duplicatable (multiple white boards if needed); scaling should be via gesture and also via numeric input option. ● White board can be snapped at specific angles - <u>these angles can be user customisable</u> ● <u>In 3D space, the whiteboard should be generated together with lighting to</u>	

	make the content visible to the user(s) independent from the scene and context they are in.		
Supporting Materials	Reference tools: [PureRef], [Annotate tool in Blender]		
User Satisfaction	Scale from 1= uninterested to 5 = extremely pleased)	User Dissatisfaction	Scale from 1 = hardly matters to 5 = extremely displeased
ZHA	5		5
AKT	5		5
SWE	5		4
Existing	PureRef	To be developed	Extend functionality in Unreal
Related Task	T4.4	Responsible Partner	CERTH
Dependencies	Tagging and query tools, Toggle Camera Perspective tools, Web Browser connection		
Conflicts (Consistency)	No particular conflicts with other requirements seem to arise with the development of this requirement.		
History	Creation changes, deletion, etc.		
Relevancy to the project	It is relevant, however T4.4 is overloaded with many functional requirements. We will seek to lower the burden using PureRef.		
Feasibility	PureRef is already a compatible tool with Unreal Engine, so it will be feasible to create a White board tool based on PureRef. Nevertheless, it could be adapted to a more useful tool inside the PrismArch project. Adaptations like the ability to access web browsers for searching information and import them to the White board Tool in a Virtual Reality environment could be explored and adapted to the existing tool.		

REQUIREMENT #: 14	REQ TYPE: FUNCTIONAL	USE CASE(S): ALL
Source	ZHA	
Description (Unambiquity)	**Clipping Plane tool**	

Features (Completeness)	● Creating a section from 3D assets ● Cut plane locations are saved via Tagging system and users can revisit the marked location, to alter it ● To make the most of this functionality, users can use this tool together with the *Toggle Camera Perspective tool*, *White Board tool*, *Multi selection tool* and *Design Evaluation tool* Example: an architectural designer made a massing model option and assigned a tag yesterday. Today, he or she was assigned a task to study the massing option further and wants to create a quick section drawing inside the VR environment. He/she did so using the clipping plane tool and the toggle camera perspective tool (side and top view). He/she then made hand sketches on top of the section using the *White board tool* then asked the Project Associate to review the sketches.		
Rationale	Provides ability to see and evaluate the cross-section of a 3D construction		
Fit Criterion (Verifiability)	● Cliping material works with single or multiple selected assets ● Slicing motion is intuitive and smooth - it would be nice for them to automatically snap at the tagged/ saved location ● The slicing should also be possible via numeric input for a more controlled positioning		
Supporting Materials	Tagging and query tools, Toggle Camera Perspective tool, White board tool, Multi selection tool and Design Evaluation tool		
User Satisfaction	Scale from 1= uninterested to 5 = extremely pleased	User Dissatisfaction	Scale from 1 = hardly matters to 5 = extremely displeased
ZHA	5		5
AKT	5		5
SWE	5		5
Existing	-	To be developed	Custom editor tool that can slicing the building and focus to the desired section
Related Task	T4.2	Responsible Partner	CERTH, MINDESK
Dependencies	Tracing paper tool, Tagging system		
Conflicts (Consistency)	No particular conflicts seem to be raised from the development of this requirement.		
History	Creation changes, deletion, etc.		
Relevancy to the project	It is relevant but this technology was not promised in the Grant Agreement. Therefore some open source tools could be exploited and tested if they could operate efficiently.		

Feasibility	The feature of slicing the building to show a specific section is feasible from a development perspective. The creation of a tool that focuses on the desired section of the project and toggle the visibility to the other sections. Also, the Reference tool could be compatible with this tool so when the user is slicing the building to show a specific section, the Reference tool will load only the images that are for this section only.

REQUIREMENT #: 15		REQ TYPE: FUNCTIONAL	USE CASE(S): ALL
Source	ZHA		
Description (Unambiquity)	**Spatial Orientation Tool**		
Features (Completeness)	● Showing directions with a compass ● User path tracing using a game map and/or 3D in-world display showing the current user location and path for each session (visit) on each floor level, and other disciplines' user locations ● Showing the user path, physical time inside the game, and game time should be matching to physical time UNLESS users are running simulations ● Last logged out location can be saved as a user start point The paths are kept as records that can be re-visited and analysed.		
Rationale	To assist the immersed users with wayfinding inside the project		
Fit Criterion (Verifiability)	● The game-like map works with architectural scale and units; these are generated automatically or manually inserted/augmented in the compass functionality ● User locations display following the discipline colour theme set in the Admin settings/tool ● VR experience time matches to physical time (including sun locations)		
Supporting Materials	See how various entertainment games are using maps for spatial orientation inside VR		
User Satisfaction	Scale from 1= uninterested to 5 = extremely pleased	User Dissatisfaction	Scale from 1 = hardly matters to 5 = extremely displeased
ZHA	3		3
AKT	3		2
SWE	4		3
Existing	Spatial Representation algorithms	To be developed	Unreal Engine VR custom Orientation Tool
Related Task	T5.2	Responsible Partner	MINDESK
Dependencies	Not depended to any other tool		

Conflicts (Consistency)	No merging conflicts seem to arise from the development of this requirement.
History	Maps can store the path of the users inside VR
Relevancy to the project	Relevant with the grant agreement description.
Feasibility	Spatial analysis and representation tools can be developed with the Unreal Engine Gameplay framework. In particular the development of used-driven VR interfaces can be enabled, so users can customize the above mentioned tools based on their requirements. Unreal Blueprints and Widgets can be employed during the development cycle, so as to reach the intended goal.

REQUIREMENT #: 16		REQ TYPE: NON-/FUNCTIONAL	USE CASE(S):
Source	ZHA		
Description (Unambiquity)	**Design support and evaluation tool**		
Features (Completeness)	● Measuring floor areas and volumes with indication of x,y,z values (Mindesk's annotation-style or tool can be called inside the platform) ● Bounding box (the same logic to box selection tool in the *Multi selection tool*) but with the x, y, z values and area/volume annotations ● Circulation routing, (eg. Drawing spline route and user object follows the route) ● Smart staircase 138odelling ● Toggling measurement resolution (mm, cm, m km) to explore measurement resolution ● Toggling measurement system – decimal and imperial (feet and inches)		
Rationale	Assists with spatial planning and evaluation		
Fit Criterion (Verifiability)	● Smart staircase database can be called using the query tool ● When measurement resolution changes, users can see the changes by using the floor grid size or any reference object size change		
Supporting Materials	Mindesk ongoing developments for measuring distances inside VR		
User Satisfaction	Scale from 1= uninterested to 5 = extremely pleased	User Dissatisfaction	Scale from 1 = hardly matters to 5 = extremely displeased
ZHA	3		3
AKT	5		5
SWE	5		5

Existing	Unreal Engine Gameplay framework	To be developed	Custom editor utilities in Unreal Engine
Related Task	T4.3	Responsible Partner	Mindesk
Dependencies	Mindesk's measurement tool / annotation style		
Conflicts (Consistency)	The development of this requirement does not raise any conflicts.		
History	Creation changes, deletion, etc.		
Relevancy to the project	This requirement is considered relevant to the project and the grant agreement document.		
Feasibility	This requirement can be considered as feasible since the current gameplay framework in Unreal Engine offers the required utilities to achieve the development of such a task. Based on custom editor utility widgets, users will have access to all the tools for relevant design and evaluation tasks.		

5. CONCLUSIONS

In this deliverable several user and function requirements were posed by end-users. In the upcoming deliverables of PrismArch, namely D5.1 - System Design on May 2021, these requirements should be evaluated by technical partners and incorporated to an extent to the system design. Next, they will be elaborated more precisely in D1.2 - Refined requirements.

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7. APPENDIX

7.1 Additional Information

This appendix presents a) an extensive list of incidents during an architectural project that should be incorporated as important visualization information inside VR spaces and b) a collection of software solutions; and c) various information related to use cases.

a) **INCIDENTS LIST**
https://docs.google.com/spreadsheets/d/15pKI51hpNv7FQqM-VzF434HhD_SWqhrBVmx_Dr97znQ/edit?usp=sharing

b) **SOFTWARE LIST**
https://drive.google.com/file/d/1fWdMRJHiZXsXymf_Vw1vlvovEZYSYEjn/view?usp=sharing

c) **CASE STUDIES:**

RESIDENTIAL PROJECTS

CaseStudy01_ZHA_PrivateResidentialVilla.xlsx:
https://docs.google.com/spreadsheets/d/1zvSjsmMHZru4Kr1U5GPDZxaDyyY2b9P2blf8zy3mMKg/edi t?usp=sharing

CaseStudy02_SWE_OneParkDrive.xlsx:
https://drive.google.com/file/d/1WqUSo9k7ElNxPJVNy16CQZvMaFHsIr_5/view?usp=sharing

CaseStudy02_AKT_OneParkDrive.xlsx
https://drive.google.com/file/d/1-j6F6m1uD5vWR82IxnIoUPLyFcdOaEBF/view?usp=sharing

COMMERCIAL PROJECTS

CaseStudy03_ZHA_OneThousandMuseum.xlsx:
https://docs.google.com/spreadsheets/d/1ez32fF8TzYtj_6hiR4f_k-YA22uSh8pg-ajpfIEVinU/edit?usp=sharing

CaseStudy04_SWE_BanksideYardsWestBuilding3.xlsx
https://drive.google.com/file/d/1td89MT3Bqu_oQcAE2gQpcKgRL45pTMYP/view?usp=sharing

CaseStudy04_AKT_BanksideYardsWestBuilding3.xlsx
https://drive.google.com/file/d/1-WO2qIexvndOL9zvz38lYS-jOeuaXXPm/view?usp=sharing

7.2 RIBA work plan 2020

RIBA Plan of Work 2020

The RIBA Plan of Work organises the process of briefing, designing, delivering, maintaining, operating and using a building into eight stages. It is a framework for all disciplines on construction projects and should be used solely as guidance for the preparation of detailed professional services and building contracts.

Stage Boundaries:
Stages 0–4 will generally be undertaken one after the other.
Stages 4 and 5 will overlap in the **Project Programme** for most projects.
Stage 5 commences when the contractor takes possession of the site and finishes at **Practical Completion**.
Stage 6 starts with the handover of the building to the client immediately after **Practical Completion** and finishes at the end of the **Defects Liability Period**.
Stage 7 starts concurrently with Stage 6 and lasts for the life of the building.

Planning Note:
Planning Applications are generally submitted at the end of Stage 3 and should only be submitted earlier when the threshold of information required has been met. If a **Planning Application** is made during Stage 3, a mid-stage gateway should be determined and it should be clear to the project team which tasks and deliverables will be required.
See Overview guidance.

Procurement:
The RIBA Plan of Work is procurement neutral – See Overview guidance for a detailed description of how each stage might be adjusted to accommodate the requirements of the **Procurement Strategy**.
ER Employer's Requirements
CP Contractor's Proposals

	0 Strategic Definition	1 Preparation and Briefing	2 Concept Design	3 Spatial Coordination	4 Technical Design	5 Manufacturing and Construction	6 Handover	7 Use
		Projects span from Stage 1 to Stage 6; the outcome of Stage 0 may be the decision to initiate a project and Stage 7 covers the ongoing use of the building.						
Stage Outcome at the end of the stage	The best means of achieving the **Client Requirements** confirmed If the outcome determines that a building is the best means of achieving the **Client Requirements**, the client proceeds to Stage 1	**Project Brief** approved by the client and confirmed that it can be accommodated on the site	**Architectural Concept** approved by the client and aligned to the **Project Brief** The brief remains "live" during Stage 2 and is derogated in response to the **Architectural Concept**	Architectural and engineering information **Spatially Coordinated**	All design information required to manufacture and construct the project completed Stage 4 will overlap with Stage 5 on most projects	Manufacturing, construction and **Commissioning** completed There is no design work in Stage 5 other than responding to **Site Queries**	Building handed over, **Aftercare** initiated and **Building Contract** concluded	Building used, operated and maintained efficiently Stage 7 starts concurrently with Stage 6 and lasts for the life of the building
Core Tasks during the stage **Project Strategies** might include: – **Conservation** (if applicable) – **Cost** – **Fire Safety** – **Health and Safety** – **Inclusive Design** – **Planning** – **Plan for Use** – **Procurement** – **Sustainability** See RIBA Plan of Work 2020 Overview for detailed guidance on **Project Strategies**	Prepare **Client Requirements** Develop **Business Case** for feasible options including review of **Project Risks** and **Project Budget** Ratify option that best delivers **Client Requirements** Review **Feedback** from previous projects Undertake **Site Appraisals** No design team required for Stages 0 and 1. Client advisers may be appointed to the client team to provide strategic advice and design thinking before Stage 2 commences.	Prepare **Project Brief** including **Project Outcomes** and **Sustainability Outcomes**, **Quality Aspirations** and **Spatial Requirements** Undertake **Feasibility Studies** Agree **Project Budget** Source **Site Information** including **Site Surveys** Prepare **Project Programme** Prepare **Project Execution Plan**	Prepare **Architectural Concept** incorporating **Strategic Engineering** requirements and aligned to **Cost Plan**, **Project Strategies** and **Outline Specification** Agree **Project Brief Derogations** Undertake **Design Reviews** with client and **Project Stakeholders** Prepare stage **Design Programme**	Undertake **Design Studies**, **Engineering Analysis** and **Cost Exercises** to test **Architectural Concept** resulting in **Spatially Coordinated** design aligned to updated **Cost Plan**, **Project Strategies** and **Outline Specification** Initiate **Change Control Procedures** Prepare stage **Design Programme**	Develop architectural and engineering technical design Prepare and coordinate design team **Building Systems** information Prepare and integrate specialist subcontractor **Building Systems** information Prepare stage **Design Programme** Specialist subcontractor designs are prepared and reviewed during Stage 4	Finalise **Site Logistics** Manufacture **Building Systems** and construct building Monitor progress against **Construction Programme** Inspect **Construction Quality** Resolve **Site Queries** as required Undertake **Commissioning** of building Prepare **Building Manual** Building handover tasks bridge Stages 5 and 6 as set out in the **Plan for Use Strategy**	Hand over building in line with **Plan for Use Strategy** Undertake review of **Project Performance** Undertake seasonal **Commissioning** Rectify defects Complete initial **Aftercare** tasks including light touch **Post Occupancy Evaluation**	Implement **Facilities Management** and **Asset Management** Undertake **Post Occupancy Evaluation** of building performance in use Verify **Project Outcomes** including **Sustainability Outcomes** Adaptation of a building (at the end of its useful life) triggers a new Stage 0
Core Statutory Processes during the stage: Planning Building Regulations Health and Safety (CDM)	Strategic appraisal of **Planning** considerations	Source pre-application **Planning Advice** Initiate collation of health and safety **Pre-construction Information**	Obtain pre-application **Planning Advice** Agree route to **Building Regulations** compliance Option: submit outline **Planning Application**	Review design against **Building Regulations** Prepare and submit **Planning Application** See **Planning Note** for guidance on submitting a **Planning Application** earlier than at end of Stage 3	Submit **Building Regulations Application** Discharge pre-commencement **Planning Conditions** Prepare **Construction Phase Plan** Submit form F10 to HSE if applicable	Carry out **Construction Phase Plan** Comply with **Planning Conditions** related to construction	Comply with **Planning Conditions** as required	Comply with **Planning Conditions** as required
Procurement Route: Traditional	Appoint client team	Appoint design team			Tender; Appoint contractor			Appoint **Facilities Management** and **Asset Management** teams, and strategic advisers as needed
Design & Build 1 Stage					ER; CP; Appoint contractor			
Design & Build 2 Stage			ER	Pre-contract services agreement	CP; Appoint contractor			
Management Contract / Construction Management			Appoint contractor					
Contractor-led			ER	Preferred bidder	CP; Appoint contractor			
Information Exchanges at the end of the stage	**Client Requirements** **Business Case**	**Project Brief** **Feasibility Studies** **Site Information** **Project Budget** **Project Programme** **Procurement Strategy** **Responsibility Matrix** **Information Requirements**	**Project Brief Derogations** Signed off **Stage Report** **Project Strategies** **Outline Specification** **Cost Plan**	Signed off **Stage Report** **Project Strategies** Updated **Outline Specification** Updated **Cost Plan** **Planning Application**	**Manufacturing Information** **Construction Information** **Final Specifications** Residual **Project Strategies** **Building Regulations Application**	**Building Manual** including **Health and Safety File** and **Fire Safety Information** **Practical Completion** certificate including **Defects List** **Asset Information** If **Verified Construction Information** is required, verification tasks must be defined	**Feedback** on **Project Performance** **Final Certificate** **Feedback** from light touch **Post Occupancy Evaluation**	**Feedback** from **Post Occupancy Evaluation** Updated **Building Manual** including **Health and Safety File** and **Fire Safety Information** as necessary

RIBA Architecture.com

Core RIBA Plan of Work terms are defined in the RIBA Plan of Work 2020 Overview glossary and set in **Bold Type**.

Further guidance and detailed stage descriptions are included in the RIBA Plan of Work 2020 Overview