

1.0 Project Management

1.1. Context

“We implement what we plan, we pursue actions not theories”. (HH Sheikh Mohammed bin Rashid Al Maktoum)

The Emirate of Dubai, UAE prides itself on being a World leader in developing new technologies / techniques for all industries. The construction industry in the UAE is a \$44 billion industry that employs approximately 34% of the population. The Dubai Government therefore is continually looking for ways to innovate and improve the efficiencies of the industry, and by 2030, the Dubai Future Agenda aims to have 25% of Dubai’s construction made by 3D printed technology. Globally, 3D printed technology is estimated to add \$300 billion to the world economy by 2025.

Located in a prominent position in the heart of Dubai, the Office of the Future is the world's first 3D printed office building. 3D printing is an innovative method which has been adapted for construction, and used here for the first time in a commercial project. The Office of the Future was created on behalf of the Dubai Government, under the patronage of His Highness Sheikh Mohammed bin Rashid Al Maktoum, Prime Minister and Vice President of the United Arab Emirates and the Ruler of Dubai.

The Office of the Future project consists of approximately 300sqm of office space, printed layer by layer using a 20-foot-tall 3D printer, located in Shanghai, China. Each structural component was built using innovative 3D printing technology, combining a mixture of Special Reinforced Concrete (SRC) and recycled construction material.

Now complete, the building serves as the management office for the ‘Museum of the Future’ project and provides a headquarters for the Dubai Future Foundation, an organization that will help to deliver smart technologies to the Emirates, including driverless cars and other cutting edge technologies.

1.2. People

“The future does not wait for those who hesitate and stall. Today, we persevere in our path we have taken to strengthen our economy and our global competitiveness”. (HH Sheikh Mohammed bin Rashid Al Maktoum)

This project was unique in that it required companies to participate based on a desire to be a part of a new method of construction. At the time of agreeing to participate, it was unclear what the outcome would be, or even if the office would be completed. This highlighted the need for innovative, forward thinking individuals within the construction industry, and individuals who were prepared to be bold.

The list below highlights the companies from all over the world who put themselves forward and were accepted to be a part of this exciting initiative:

Dubai Prime Minister’s Office (Client)	NEC (Equipment Supplier)
Jumeirah (Landlord)	Ventura (Equipment Supplier)
PMKConsult (Project Manager)	Huawei (Equipment Supplier)
Winsun Global (3D Printing Supplier)	Siemens (Equipment Supplier)
E-Construct (Engineer)	Reynard Lighting (Lighting Supplier)
Projex (Fit Out Contractor)	BASF (Grout Supplier)
China State Construction (MEP Contractor)	Golden Elements (Render Applicator)
China State Construction (Civil Contractor)	NPPF (Render Supplier)
Desert Landscape (Landscape Contractor)	Gulf Precast (Concrete Specialist)
Cracknell (Landscape Designer)	CSS (Shipping Company)
Thornton Tomasetti (Designers)	Fressinet (Post Tensioning Supplier)
Gensler (Designers)	ABB (Lighting Control)
Killa Design (Designers)	Daikin (Air Conditioning)
Syska Hennessy (MEP Design)	Comms scope (Equipment Supplier)

IT Serve (IT Design)	Schnieder (Equipment Supplier)
Puckrin Design (Interior Designer)	Ulster (Carpet Supplier)
Zoluti (Furniture)	Ducab (Cable Supplier)
Oxford Glass (Glazing Supplier)	Bene (Interactive Idea Wall)
Mace (Door entry specialist)	Eversendai (Lifting Brackets)

There was a strong international influence throughout the project team. The core company team members brought with them their own strong native governance procedures which meant overcoming multicultural barriers was critical to the success of the project. This was recognised very early in the project lifecycle and it encouraged open and honest dialogue from the beginning.

Within this project, it was essential to communicate using management and leadership techniques in order to motivate and inspire people to perform to their potential, within the short time frame. Whilst leading the project, there was a constant need to focus on both the project and business fundamentals. To give the project the best chance of success it was essential to utilise the basic functions of management: leading, planning, organising, staffing, controlling and communicating. In a multicultural society and in a ground breaking new innovative 3D printing sector, a clear communication strategy flow was essential. Through clear communication the Prime Minister’s Office promoted discipline and accountability.

The Prime Minister’s Office was open to PMKConsult relating to their business activities, so that we could plan and align design, procurement and construction activities accordingly, prioritising those which would have the greatest impact.

The motivation for being a part of this project was unique and unusual, as there was no financial gain for anyone involved in the design, procurement or construction of the ‘Office of the Future’. Therefore, the motivation for the project team was more about gaining experience and skills than monetary success. This created a different dynamic based around creativity, shared success and collaborative working in order to get the most out of this unique set of circumstances within a project.

1.3. Delivery

PMKConsult has a detailed and systematic procedure for Project Management. This involved identification of a visible project leader, implementing Project Execution Plans, Communication Plans, Progress Reports, Risk Management, Flowcharts, Organograms and a Responsibility Matrix. As Project Manager, PMKConsult led the process to plan and organise the design and construction programme for a completely new and untested 3D printed office building.

However, recognising that this project uses a technology never before used in a commercial venture, PMKConsult had to adapt the more traditional flow of a project to adapt to the unknowns in the programme. For example, the 3D technology had not been proven structurally. The Dubai Municipality simply did not know the process for structural testing and so this was time consuming. How would the components react when post tensioned on site, how much tolerance would each unit have, and how easy would they be to work with? All of these questions had no answer as, unlike traditional construction methods, nobody have ever delivered a building of this nature.

Project management and leadership therefore was key, and PMKConsult simply had to adapt their traditional approach into a more flexible, personal and proactive style of management.

We started by planning out the process of concept, schematic and detailed design stages of each design package. In order to be able to measure performance against this plan, PMKConsult planned, organised and chaired design co-ordination workshops, produced design gateway reports for client approval, and set client approval periods which were required before moving on to the next stage of design. To build team relationships, PMKConsult arranged regular social events following each design coordination workshop.

The programme performance was measured and monitored against pre-determined key deliverable dates which had been outlined in collaboration with the rest of the project team. PMKConsult worked closely with the Client and developed a team to undertake each specific area of the design deliverables. In order to monitor progress, a design and responsibility matrix was created to identify roles, responsibilities and delivery dates for each team member. This matrix enabled the team to clearly see who was responsible for designing each element of the building. It also highlighted areas which still needed to be assigned to an owner. This aided smooth transition from detailed design to construction and delivery.

Once the 3D cassettes were printed, the internal fit out and external designs were adopted. Upon delivery to the UAE, the cassettes needed to be post-tensioned and put through a series of structural tests. Once certified as fit for purpose, the cassette units were transported to site and assembled. The project deadline was the date of inauguration by His Highness Sheikh Mohammed bin Rashid Al Maktoum. This date was fixed, as His Highness was scheduled to attend the project and inaugurate the building, whilst greeting the world's press. Overall, the project was delivered on time and to the required standards of the client. Whilst there was no formal overarching budget set by the client, each package was managed to a pre-agreed budget ceiling cost which was met across each package.

1.4. Interfaces

A key challenge within this project was the interface between our team and the Dubai Municipality.

Firstly, Dubai Municipality (DM) is the organisation responsible for issuing structural and occupancy certificates in Dubai. They simply did not understand the technology and did not have the ability to certify an unknown construction technique. PMKConsult and the wider team not only had to demonstrate how the building performed structurally, but actually had to design the structural testing technique, educate DM on how this worked and then guide them through the certification process. This was a timely exercise and could be likened to changing a building regulation in the UK for a single project.

Secondly, the Road and Transport Authority (RTA). The location of the project site was adjacent to the main highway in Dubai, and there was a regular need for road permits to enable HGV and Crane access to and from the site. To overcome this barrier, we identified and agreed set dates at an early stage for when we would need access permits. There were also interfaces with the Government departments regarding telephone connections (Etisalat), and the electricity and water supply connections (DEWA) which needed to be efficiently managed. To obtain these approvals, we were required to develop tools to track and manage the process of applying for and receiving approvals from the local authorities. We fostered relationships between the consultants, contractors and local authorities which contributed to a clear understanding from all parties, and the required actions from each party.

2.0 Results and Benefits

"...benefit at the regional and international levels on real application of 3D printing technology".
(HH Sheikh Mohammed bin Rashid Al Maktoum)

The global significance of the delivery of this building cannot be underestimated. The Government of Dubai have taken an unproven technology and demonstrated through vision, determination and leadership, that 3D printing can and will perform a key function in the delivery of buildings in the future.

3D printing of buildings can be likened to the early mobile phone technology of the 80's and 90's. The first mobile phone was the size of a small family car, heavy and impractical. If Motorola had not had a vision for how this technology would develop in the future, the smartphones of today would possibly not be in existence. 3D printing is the same, and the significance of this project will have the same impact on the global construction industry.

From a practical perspective, an inspirational office building has been created. This is fundamental for the creative space in which the Dubai Future Foundation will collaborate and foster innovative ideas and concepts for design and application in the future. This project benefitted the client hugely as it was the first ever 3D printed office building, and the finished product has been documented globally and reported

upon across the world. Not only has this benefitted the Dubai Future Foundation, it has elevated Dubai and the Middle East once more as a pioneer and leader in innovative design, technology and construction. This has benefitted the client and enabled them to lead the way at the forefront of global innovation in construction methods.

Below are two photographs of the completed 'Office of the Future Project' which is overlooked by the prestigious Emirates Towers building, which houses the Prime Minister's Office. As you can see, the result of this project is a unique, futuristic, compact office building. The exterior shape and design of the structure was successfully produced using 3D printed technology to the specification given by the client.



The interior of the building follows a minimalistic design which encourages collaborative working and creative thinking. Features include; interactive idea walls, open plan communal areas with natural foliage, large glass windows to allow natural light, fully automated building management systems to regulate temperature, lighting, solar shading and audio-visual equipment.



"...serve as a reference point to take this technology to new levels". (HH Sheikh Mohammed bin Rashid Al Maktoum)

A huge benefit of utilising 3D printing methodology was the speed at which the building was completed. Once the design model had been received, it took only seventeen days to print the entire structure. Once the structures had been shipped to the UAE, the speed of installation on site took two days. The

speed of installation also significantly reduced the number of personnel involved in the site installation phase. Specifically, the labour involved in the printing process included just one staff member to monitor the function of the printer, plus seven people to install the building components on site. As a result, the labour cost was cut significantly compared to conventional buildings of similar size, which has clear implications for the future of construction.

Throughout the project, the team embraced and benefitted from a 'no blame culture' in order to maintain a positive working environment which encouraged multi-disciplinary collaborations. This approach is often cited as a key element to success, however rarely can it be seen as reality on construction projects. This was a unique feature of the project.

"We begin to implement the Dubai Future Agenda through initiatives and strategies that add value to human life and to our national economy". (HH Sheikh Mohammed bin Rashid Al Maktoum)

Through working on the project, and being associated with its completion, the companies and individuals involved are part of a unique and specialist network of professionals. They have a unique awareness of the benefits and constraints associated with this novel method of 3D printed construction. They have formed a network of '3D printed construction' professionals, who have demonstrated their ability to work together and bring about real world solutions in a challenging high pressure environment. They have

added value to the national economy within Dubai, and hopefully will be able to continue to do so globally in the future.

The nature of an overseas project means that the results and benefits are felt globally. The 3D printed units were printed in China, the office building was designed in the USA, engineered by an Egyptian engineering company, project managed by a British project management company, and installed by a Chinese contractor employing Indian labour, on a construction site in the UAE. A truly global supply chain that required an appreciation of multicultural working practices across different time zones.

3.0 Innovation and Lessons Learned

“The rapidly changing world requires us to accelerate our pace of development, for history does not recognise our plans but our achievements”. (HH Sheikh Mohammed bin Rashid Al Maktoum) **3.1.**

Lessons Learned

Fundamentally, we have learned that it is possible to design, create and build a 3D printed office building. We now know that it is possible to print and install a building within 17 days, which provides valuable data and a realistic benchmark for time frames for future 3D printed building projects. We also learned about the capability of 3D printing, for example we ran a prototype to 3D print the façade of the building, which was unsuccessful because it could not be done within the time frame. Therefore, we learned that the possibilities for 3D printed buildings can far exceed what has been achieved here, if there is a longer time frame allowed for completion.

To document and share key information, the project manager created and shared a presentation to his team regarding the ‘Office of the Future’ project. This presentation will also be shared with external colleagues and professional groups, as it is an innovative method of construction and therefore important to share this knowledge with others who do not have this knowledge. This also allows the opportunity to gain other people’s views, ideas and feedback which will influence the future of the industry.

3.2. Managing Innovation

“This is an experience we present to the world on implementing future technology in our lives, and it represents a new milestone for the UAE as a global leader in strategic achievements”. (HH Sheikh Mohammed bin Rashid Al Maktoum)

As outlined, this project was entirely innovative in its approach, structure and delivery. The approach was innovative in that it utilised an alternative methodology of design, procurement and construction. In order to manage the innovative nature of this project, we had a continual lessons learned database where we documented new data and added this to a project library. An example of this was that the span of the 3D printed cassette was the largest ever produced by a 3D printer, and there was no previous structural performance data to guide the team. Therefore, we carried out a series of structural tests in China and the UAE to meet the stringent British Standards. A lesson learned here was the importance and value of previous documentations and standards regarding performance of building materials. Without the historical documentation from previous projects, the future of construction cannot develop. This highlighted the importance of documenting the outcome of the structural performance data for this project, as hopefully 3D printing will evolve and the data provided can be a source of accurate information for future projects to base their design calculations upon.

A key challenge for this project as Project Managers was to effectively manage a large team of people, across a number of disciplines who were contributing to the project essentially to gain experience and to promote their companies as opposed to gaining immediate financial reward. This was a new way of working, which differs to the typical way of procuring goods or services via a defined scope and price. This proved to be a more challenging, yet very rewarding way of working, however it had to be managed differently. In order to manage this, essentially we interviewed all of the key people before they agreed to be a part of the project. This was to ensure that project team members were fully aware of the innovative

nature of this project, what the difficulties and challenges were perceived to be, and what would be expected of them. We had to ensure that the people who were involved with the project were aligned to the idea that the benefit to them would be the possibility of involvement in any future projects, rather than immediate gratification for being a part of the project. We used the interview method to appoint team members, and this enabled us to have the right people working on the project, and minimised the risk of unsuccessful team members.

As this was the first of its kind, the project structure and procurement strategy was equally innovative. Specifically, the project relied upon procuring goods and services at a heavily reduced price or 'good will gesture' as opposed to monetary payment. Vendors were encouraged to compete for selection by demonstrating their innovative products and services, and in return they were awarded the opportunity to be part of the project team involved in pioneering the delivery of the world's first 3D printed office building. As the project was successfully completed on time and to the standards of the client, this method of managing the innovative nature of the project was a success. The wider profession may benefit from this method because vendors may change their focus from an immediate financial gratification, to a more open minded, 'bigger picture'.

3.3. Challenges Overcome

A few challenges and difficulties were anticipated due to the nature of the project. Firstly, the lack of historical data of the 3D printed cassette units of this size was a challenge we knew we would have to face. We were able to overcome this challenge by undertaking our own structural tests and collating our own data from which to work from. This was a risk that was highlighted in the risk register from the outset that had to be managed throughout the process with a risk owner, rating and mitigation plan. Another example of an anticipated challenge was the need to obtain permits from the RTA in order to transport the 3D printed units from the holding yard to the site. In order to do this, we contacted the RTA as early as possible and negotiated a date and time slot whereby we would be granted a permit.

As this was an innovative method of construction, the team did not have the full knowledge or expertise regarding the structural performance of the 3D printed elements. We therefore identified a general learning need of the team, and organized for the Resident Engineer to visit the 3D printing factory in China. This enabled a key team member to perform a series of structural tests, which consequently informed the details of the remaining design.

Unfortunately, during a critical time within the project, the UAE was brought to an absolute standstill due to the worst storms they have experienced, with 126kph winds, submerged cars and flying debris. This presented an unforeseen challenge as we lost time in the programme, however through accelerated working we made back the time and opened the building on time as planned.

Final Thoughts

Ultimately, for PMKConsult, this project was an overwhelming success. We delivered the world's first ever 3D printed office building, overcame many challenges, and demonstrated our position as the Project Management Company at the forefront of innovation in construction.

PMKConsult are proud to be a company which is flexible to the needs of their clients. We continually strive to utilise a tailored approach for each project we work on; this project in particular highlights the effectiveness of this strategy. It would have been impossible to use a 'one size fits all' approach for a project of this nature. We are thrilled at the positivity expressed by His Highness Sheikh Mohammed bin Rashid Al Maktoum, and the quotations dispersed throughout this report are his own words.

The 'Office of the Future' project represented one of the most relevant and exciting research and development construction projects anywhere in the world. With this was an aim to bring about a culture of success by association within the project team. The team were proud to deliver the project and they worked hard; continually striving for better achievements and the benefit of seeing the bigger picture of their involvement in the project and the impact they may have in the future of global construction.