21 Concept to Realisation: GRC and Complex Facades

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ABSTRACT

Buildings with complex geometry need careful coordination during the design phase to ensure a successful construction phase. Even though the facades of the King Abdullah Petroleum Studies and Research Center (KAPSARC) have a complex faceted geometry with few parallel planes, they are buildable out of GRC because of careful research and coordination between architects and engineers during the design phases. The design of projects that have complicated geometry can suffer if coordination does not occur early enough in the design process. Undesirable compromises can creep in, especially in the construction process, which can then undermine the architectural intent. This was avoided in the design of the facades of KAPSARC through careful design, research, and coordination between the architects and façade engineers.

To achieve the original aesthetic intent of the facades of the KAPSARC project, Zaha Hadid Architects worked with Arup Facades Engineering to determine façade systems and materials and develop a set of facades design parameters early in the design process. The selection of the façade materials and systems and the parameters regarding elements of the façade including use of GRC as the cladding material, the sizing of the GRC panels, the punched window design and interface with the GRC, and the joint sizes between the GRC panels, were fed into the architect's renderings and 3D models of the facades. Then the rules developed to establish the parameters GRC of the facade were used by the design team refine the aesthetic appearance of the façade.

In addition, other metrics such as thermal performance of the façade were taken into account. Technical and performance drivers also influenced the selection of GRC, from climate issues to sustainability requirements. For example, rules regarding percentage of glazing to opaque walling and wall build-up were also developed by the engineers and coordinated with the architect. In this way a coordinated façade was designed that both met the aesthetic requirements as well as the functional requirements.

INTRODUCTION

KAPSARC is a center for energy and environmental research and policy studies in Riyadh, Saudi Arabia. The client is Saudi Aramco, the national oil company of Saudi Arabia and a global oil company that manages the world's largest crude reserves.[i] At KAPSARC, environmental experts will come from around the world to research energy and the environment. The researchers at KAPSARC will also engage in collaborative research with similar research centers around the world.[ii] As a center for energy research the complex has a sustainable agenda and is targeting a LEED (Leadership in Energy and Environmental Design) rating of Platinum, the highest rating possible. The LEED rating reflects the projects goals of being in the forefront of sustainability and design, as well as research. LEED impacted all aspects of the design, from the layout of buildings and landscaping on the site to the mechanical systems. The façade design was also heavily impacted by LEED requirements.

Figure 1: The KAPSARC complex from a bird's eye view, showing the Research Center in the upper right of the image. Render © Zaha Hadid Architects.

The KAPSARC complex consists of five main buildings and several site buildings, with over 70,000 square meters of GRC facades. The main buildings at KAPSARC are the Research Center, Library, Conference Center, IT Center, and Musalla. The primary building on the KAPSARC campus is the Research Center. Over 200 meters long, this building is the main hub for the researchers. Over 300 researchers will have their offices here. To the south of the Research Center is the Conference Center. The second largest building, the Conference Center is used for major conferences on site and has a 335 seat auditorium and a Multipurpose Hall that can seat 730 people for banquets and other events. Adjacent to the Conference Center is the Musalla, the main worship space of the project which features sheltered outdoor courtyards for gathering as well as ablution rooms and an interior place of worship facing Mecca. The IT Center is the technology hub of the project, with complete back-up facilities in the IT Utility building. To the north of the IT Center is the Library, which serves as the educational center of the project. Book stores are maintained in the basement below and book stacks in the levels above. The five buildings all face onto the Place of Icon, an exterior space protected from the elements by the main fabric canopy overhead.

Figure 2: View of the main canopy in the Place of Icon. Render © Zaha Hadid Architects.

The general massing of KAPSARC evolved as a cellular courtyard concept, which takes advantage of the benefits of the location in the desert (such as mild winters) while protecting the users from the harsh surrounding environment. Each building is made up of clusters of 6-sided cells which range from 1 story high in the site buildings to 4 stories in the Research Center. Cells often have a courtyard at their center or an enclosed atrium with a roof light above.

During the competition and the early stages of design the KAPSARC facades were very conceptual, with a general idea about geometry and pattern expressed but no materials selected or performance requirements met. In general there was a concept of a pattern of screens or windows that flowed over a façade surface. As the project progressed, the facades had to be more concretely defined. One of the first major decisions had to do with materiality.

ROOF AND WALL BUILDUP

The architectural intent for the KAPSARC facades called for a monolithic and seamless façade with a secondary pattern flowing over the monolithic surface. This secondary pattern created a texture across the surface that harmonized with the overall geometry of the buildings and corresponded with the interior requirements. Some areas have a very dense pattern and other areas have a very sparse pattern, depending on factors such as façade orientation and program behind the facade. A unified façade design was desired for all buildings on the site, though each building has a different purpose. To achieve this, various wall build-ups were investigated.

One complication in this process was caused by the varying angles of the roof and facades. In the building's forms of KAPSARC it is not easy to determine what elements are considered "roof" and which elements are "façade" due to the non-rectilinear geometry. The external facades slope both in and out at varying angles. The pitch of the roofs also varies from surface to surface. An effort was made by the architect to standardize the angles but in general the geometry is variable from façade to façade. Due to this varying geometry of the roofs and facades, a substrate was required that could be applied to all facade surfaces and also that could accommodate the non-repetitive geometry of the envelope.

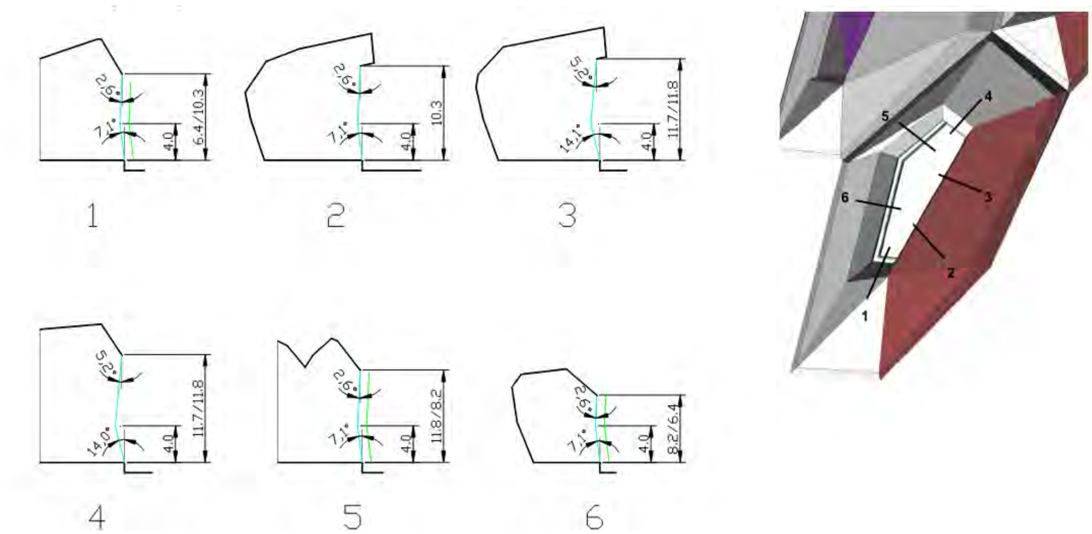

Figure 3: A typical open courtyard with sections through each face showing the varying geometry. Image © Arup Facades Engineering.

One of the other major drivers of the façade was the LEED-driven ambitious thermal performance required for the opaque roof and walls. Among other things, this performance requirement meant minimizing penetrations through the weathering line, which could not be a simple membrane as it needed to support the external architectural finish.

Several solutions for the façade substrate were considered, from precast to unitized curtain walling. These options were compared, and the positive and negative aspects of each system explored. A standing seam system was ultimately chosen because it could be simply applied to the faceted surfaces. Additionally, many precedents showed that fixing a rain screen architectural finish to the standing seam substrate below was achievable, even when strict performance requirements were taken into account.

Figure 4: Facade under construction at the China Academy of Fine Arts showing a stone architectural finish clipped to a substrate. Image courtesy Tony Mills.

SELECTION OF ARCHITECTURAL RAINSCREEN

The facade system selected consists of a standing seam layer that seals the building and a material affixed on top of the standing seam that forms the outside architectural skin of the building. Several materials were explored to achieve the design intent of the outside skin. The architect desired a material that could flexibly incorporate pattern while the client desired a material that could quickly and easily be procured, especially with respect to production and time frame. From a technical point of view, it is essential that the materials used for the façade on any project are selected early on in the design process. This is especially important on geometrically complex buildings such as KAPSARC. The choice of material should be influenced not only by aesthetic factors, but also by technical factors such as the performance requirements, geometrical requirements, the environment the facade is subject to, and the design life of the cladding.

To meet these varied requirements, research of many materials was undertaken. A “long list” of materials was reduced to a more practical “short list” of the following materials:

1. Glass Reinforced Concrete (GRC);
2. Stone veneer with an aluminium honeycomb backing;
3. Fibre Reinforced Plastic (FRP);
4. Granite;
5. Precast Concrete.

Arup Facades developed research on these materials while also looking at issues specifically related to the KAPSARC project (for example, climate, location, and building form). Rules generated from the research were then used as design and procurement drivers for the cladding material selection. These drivers in turn informed the material selection process. The study then considered each shortlisted material, giving general information concerning manufacturing process, built precedent, manufacturing limitations, and finish options. Other criteria were also considered. To exhaust all options and clarify to the client the thought process behind the materials selection process, the following criteria were also considered and compiled into a clear materials matrix.

The materials matrix included:

- The ability of material to accommodate geometry;
- Local procurement options;
- LEED certification issues such as Solar Reflectance Index (SRI);
- Ability to be mass produced;
- UV resistance;
- Impact resistance;
- Abrasion resistance;
- Weight and impact on structure;
- Thermal performance;
- Implications on programme.

	Local & Multiple Procurement Options	LEED certification	Mass Production	UV Resistance	Impact Resistance (Trafficable/Hail)	Abrasion Resistance	Durability	Weight and impact on roof structure	Performance	Programme implications
GRC (Glass Reinforced Concrete)	GRC is commonly used in the region and there are various suppliers who could provide a competitive tender.	Potentially good for LEED certification as product can be locally sourced.	Can be produced in large quantities locally with good precedent for large scale buildings.	UV resistance is good with evidence of this in the region.	Generally good impact resistance. Can be designed to be thicker in locations where high levels of impact are expected.	Likely to have good abrasion resistance to sand at low levels. Built precedent in the region can be assessed to make sure it is o.k.	Good durability and built precedent within the region confirms its suitability to local conditions.	Low weight	If combined with standing seam roof good performance could be achieved.	Good as weather and thermal line can be installed ahead of aesthetic and shading over-cladding.
	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓
Stone	Stone is commonly used in the region and there are various suppliers in the Middle East who could provide a competitive tender.	Potentially good for LEED certification as stone could be sourced locally and potentially fabricated in the Middle East.	Can be produced in large quantities locally but it important that sufficient lead-in times are allowed for to work within the stone fabricators production capacities.	UV resistance is good	Stone cladding can be tested for its impact resistance (BS 8200) and can be designed against impact damage if required (e.g. impact pads)	Granite is likely to have good abrasion resistance.	Granite as a cladding material has a good durability worldwide and in the region. Project specific testing will be required to confirm the durability of the Saudi Arabian granites.	Medium	If combined with standing seam roof good performance could be achieved.	Good as weather and thermal line can be installed ahead of aesthetic and shading over-cladding.
	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓	✓✓✓	✓✓✓	✓	✓✓✓	✓✓✓
Stone Aluminium Honeycomb Composite	There are no known suppliers within the region and only experience of one company in North America.	Stone could be locally sourced which could be advantages for LEED certification but likely that it will have to be transported to North America for processing.	Mass production is possible but only in North America	UV resistance is likely to be good. There is no known examples of the product in the region but it is heavily used in parts of North America where the climate is not dissimilar.	The stone itself is very thin and may crack under impact but the aluminium honeycomb backing is very strong and good against impact damage.	Likely to have good abrasion resistance but could depend on the stone type chosen. Testing and assessing any local natural stone clad buildings in the region may be required.	Proven durability in North America but no known built precedent in the region. Due to the severe conditions further testing of the adhesive bond may be required.	Low weight	If combined with standing seam roof good performance could be achieved.	Good as weather and thermal line can be installed ahead of aesthetic and shading over cladding.
	✗	✓	✓	✓✓✓	✓	✓✓✓	✓	✓✓✓	✓✓✓	✓✓✓
FRP (Fibre Reinforced Plastic	There are no known suppliers in the region with knowledge of only three companies in Europe.	Cannot be locally sourced and production/ processing techniques	Due to manufacturing process mass production would be difficult unless a lot of repetition is used even then this is a hand finished product and would be difficult to produce in mass.	Due to the finish applied to the FRP it is likely that this will fade over time and need repainted. There are no known examples of FRP cladding in a climate similar to the Middle East.	FRP can be designed against impact damage where there is a risk of high levels of impact.	Resistance to abrasion currently unknown but likely to be poor due to the nature of the finish to the product. Testing and further information would be required.	Proven durability in the UK and Europe. Likely to need repainting every 15-20 years and maybe more with the severe conditions in the region. No known built precedent in the Middle East.	Low weight	If combined with standing seam roof good performance could be achieved.	Good as weather and thermal line can be installed ahead of aesthetic and shading over-cladding.
	✗	✗	✗	✗	✓✓✓	✗	✓	✓✓✓	✓✓✓	✓✓✓
Precast Concrete	Precast Concrete is commonly used in the region and there are various suppliers who could provide a competitive tender.	Potentially good for LEED certification as product can be locally sourced.	Can be produced in large quantities but larger size of panels will result in less repetition than smaller sized cladding materials.	UV resistance is good with evidence of this in the region.	Very good.	Very good.	Very good.	Heavy weight—this would require a stronger roof structure and would affect the overall depth of both cladding and main structure.	Not easily combined with standing seam roofing. Alternative weather tightness design would be required.	Precast concrete would be on the critical path and could risk delaying later trades.
	✓✓✓	✓✓✓	✓	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✗	✓	✗

Figure 5: The materials matrix. Image © Arup Facades Engineering.

In essence, a wide variety of technical factors were researched in order to narrow the cladding material options. As can be seen from the matrix, GRC performed better than any of the other materials in all categories. At this point the material choice was clear, since GRC also met the architectural intent. Once GRC was selected as the cladding material, the GRC-specific procurement options were investigated.

PROCUREMENT

There were several elements of the procurement process which the design team took into account when selecting the facades systems and architectural cladding material. Three main issues included local procurement of materials, the ambitious timeframe of the project, and the large scale of the KAPSARC project.

As the project is located in Saudi Arabia, there was a strong desire to procure the cladding for the building locally. This meant that the architectural cladding material and substrate system should ideally be a technology that is established and readily available in the region. Because the scheme targeted a LEED Platinum rating and sustainability is prioritized on the project, locally obtaining as many materials as possible was desirable.

Secondly, the project programme was very ambitious, which suggested the use of an “off the shelf system” or simple derivative thereof. There was little time available for bespoke system development and research. The client desired a system that was as standardized as possible and quick to construct.

Finally, the scale of the project is very large and therefore there is a subsequent need for mass production of cladding components and panels. This suggested a large fabrication facility with significant available capacity, and multiple procurement options (to maintain competitive pricing).

Other materials in the shortlist were not so easily procurable, in many cases addressing only one or two of the above concerns. For example, Saudi Bianco granite was considered as a cladding material, and quarries are active within the 500 mile radius of the site. From a sustainability point of view this material would be desirable. However, the amount of time it would take to extract and process the granite was considerably longer than the production of GRC. This was deemed a risk to the programme of the project, and for this and aesthetic reasons the material was ultimately not considered for the façade cladding.

PERFORMANCE

Along with procurement concerns, technical performance had a major impact on the KAPSARC facades. Some of the concerns at the forefront of the investigation included climate, aesthetic, and sustainability issues.

The climate in the Riyadh area is very hot and dry with high levels of UV radiation. Rainfall is minimal and usually isolated in infrequent but intense storm events. The high UV levels at the site suggest a self-finished material, rather than a coated or painted product, which would fade and discolour over time.

The Riyadh area is also subject to frequent large sand and dust storms. These storms deposit large quantities of material onto the building roofs, which was addressed in the design of the open joint system with “sand gutters” beneath the open joints. In addition, the presence of significant quantities of sand on the cladding surface suggests a material with a good abrasion resistance and a low gloss finish, as the finish would quickly become dull over time. The roof cladding panels also needed to be trafficable for cleaning and maintenance. Finally, though Riyadh is an arid climate, there are occasionally violent thunderstorms which can include large hail stones falling with high kinetic energy. This drives the need for robust cladding panels which are not easily dented or damaged from this impact. Brittle finishes are not feasible, and again a good abrasion resistance on a non-glossy finish was considered the best approach.

Along with climactic concerns aesthetic issues were also taken into account. For example, there was a desired for the roofs and walls in the scheme have the same material selection and visual appearance. This suggested a system that is equally applicable to a variety of geometries, including both vertical and horizontal surfaces. The selected cladding material was to function in an overhead soffit condition, and as such should be suitably robust, and not fracture into dangerous pieces if broken. In some areas the cladding surface covers un-insulated areas of the façade, and a material and build-up that allowed all façade surfaces to appear similar was the design intent.

One issue that combines issues related to weather with aesthetic issues has to do with thermal expansion. The excessive temperatures on site dictate large thermal expansion between adjacent cladding panels, which is accommodated in the jointing regime between adjacent units. The aesthetic means of addressing this occurred through the design of the panelization.

Finally, sustainability drivers dictate a high-performance opaque cladding system with a good air-permeability performance. Additionally, because of the LEED Solar Reflectance Index (SRI) values as well as visual design intent, the cladding material was required to be a light coloured off-white/grey colour. The design aspiration is for a finish that reflects diffuse light, rather than a specular mirrored surface. For the LEED requirements this surface was also required to reflect heat and solar energy to prevent a heat island effect that sometimes occurs in sunny climates with dark façade materials.

The above points were key to a successful material selection for the KAPSARC roof and wall cladding. After the above concerns were addressed, the next step was to establish a means of applying GRC to the geometry and further defining the joints between the GRC panels.

JOINTS BETWEEN PANELS

Once the cladding system had been chosen the next major decision was regarding open or closed joints between the GRC panels. If the joints were closed then sand would not fall through the gaps on to the standing seam trays below. However, if a closed-jointed system was selected this would rely on either gaskets or silicone applied onsite to seal the joints. Having closed joints was not preferred esthetically or technically. From a visual point of view, the architect wanted a deep joint (approximately 100 mm) to create an impression of depth to the GRC panels.

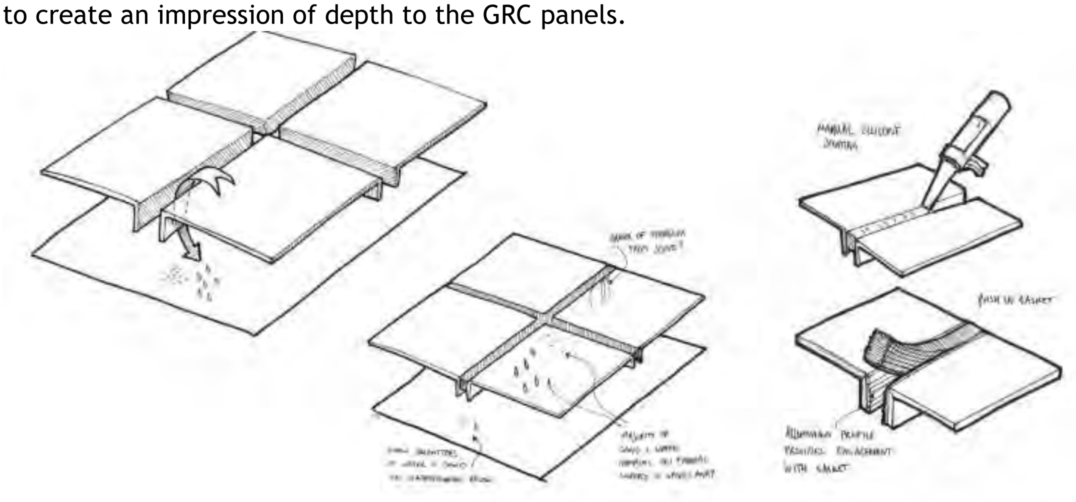

Figure 6: Joint options. Image © Arup Facades Engineering.

From a technical point of view, having closed joints can result in streaking across the façade as illustrated in the images below.

Figure 7: The open-joint system with waterproof layer below on the Sage Music Center in Gateshead, UK.

Figure 8: The National Center for Popular Music in Sheffield, UK has sealed joints which caused streaking on the facade.

Thus an open jointed system was selected. This then raised the issue of how to deal with sand that falls between the joints in the rain screen panels fixed to the standing seam trays. Even small amounts of dust would over time build up and in combination with moisture would result a hard cement-like buildup on the standing seam trays.

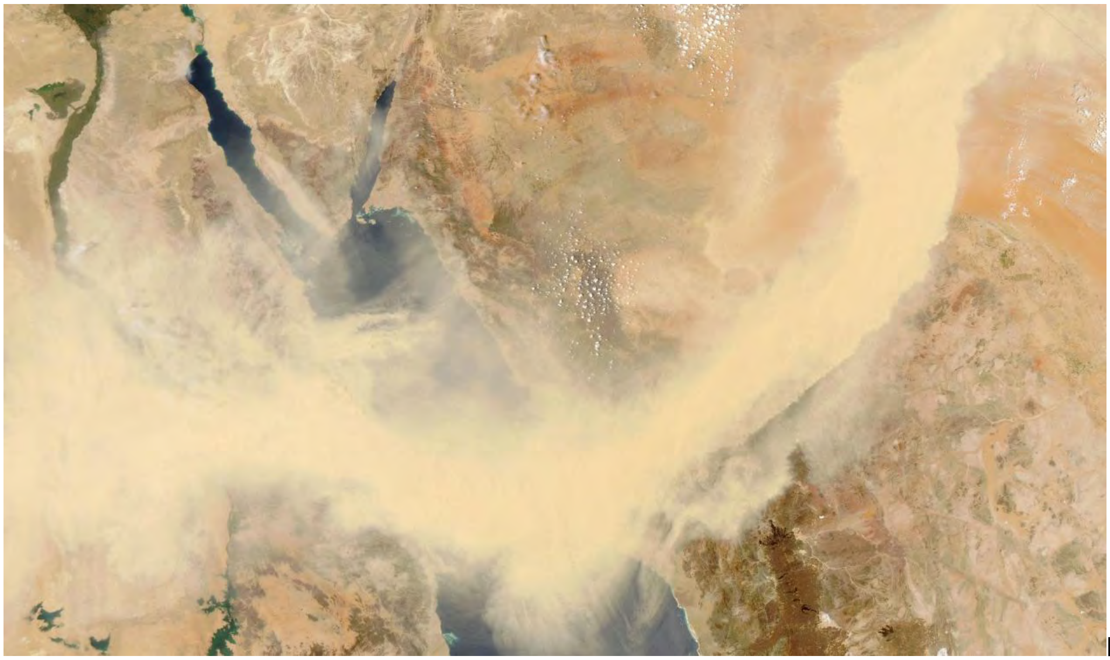

Figure 9: An aerial view of a sandstorm moving from Egypt towards Saudi Arabia.

Several solutions were considered for how to deal with the issue of sand infiltration onto the standing seam. Lifting the panels in order to access below and clean off the sand accumulation had been used on similar projects in similar climates, although these projects used a relatively light weight rain screen such as aluminium and stainless steel. In order to make a decision on how to address sand infiltration onto the standing seam tray a series of meetings was arranged with façade and roofing contractors to obtain feedback on how they would approach the issue. One solution that was proposed was to use a series of ‘sand gutters’ which were placed below the open joints in the panels.

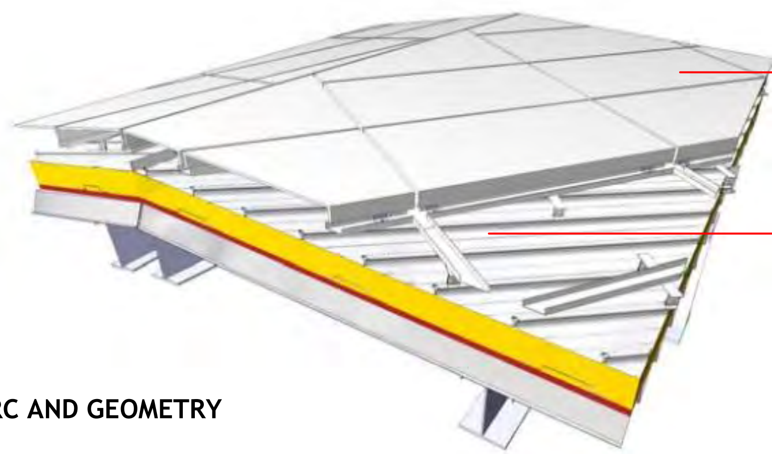

Figure 10: A 3D cutaway showing the GRC architectural cladding surface with

GRC AND GEOMETRY

After the joints between panels were resolved, a process of understanding how to apply GRC to a complicated geometry was begun. Panelization studies were undertaken in the 3D model by the architect, with rules regarding optimum size of panels from the engineer guiding the studies. The open gap or joint between the panels was also researched and set at 25 millimeters. These rules were fed into the architect’s design of the façade pattern and panelization process.

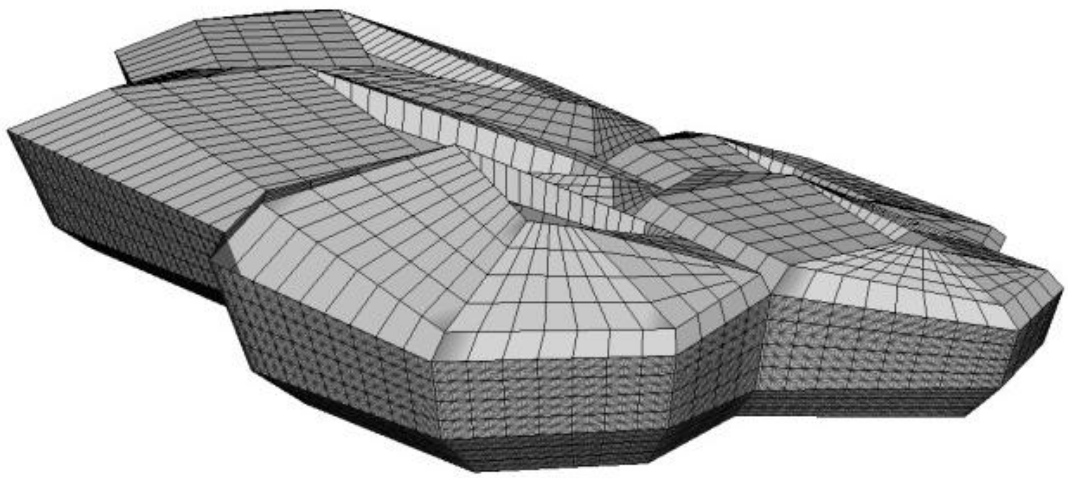

Figure 11: One of the early panelization studies of the facade. Image © Zaha Hadid Architects.

Once panel and joint sizes were set, rules regarding window openings within the panels were created. Window penetrations were studied in the 3D model. Many window sizes and shapes were studied before a suite of varying triangular windows was chosen. Then the size of the window, the quantity of windows per panel, the spacing between the windows in the panel, and the distance between the edge of the panel and the location of the windows were all established to ensure the design could be constructed, the aesthetic intent could be achieved, and the u-value requirements of the façade were met.

Figure 12: One of the preliminary facade window studies that was ultimately discarded. Image © Zaha Hadid Architects.

These parameters were applied to four typical panels, which became the basis for the entire façade of the project. The four panels included all the possible constraints—the centerline of the open joint, the possible locations of all windows, and options for a "recessed panel" which visually continues the pattern without actually becoming a full window penetration that actually penetrated the panel. These parameters were then applied to the entire façade envelope using parametric software.

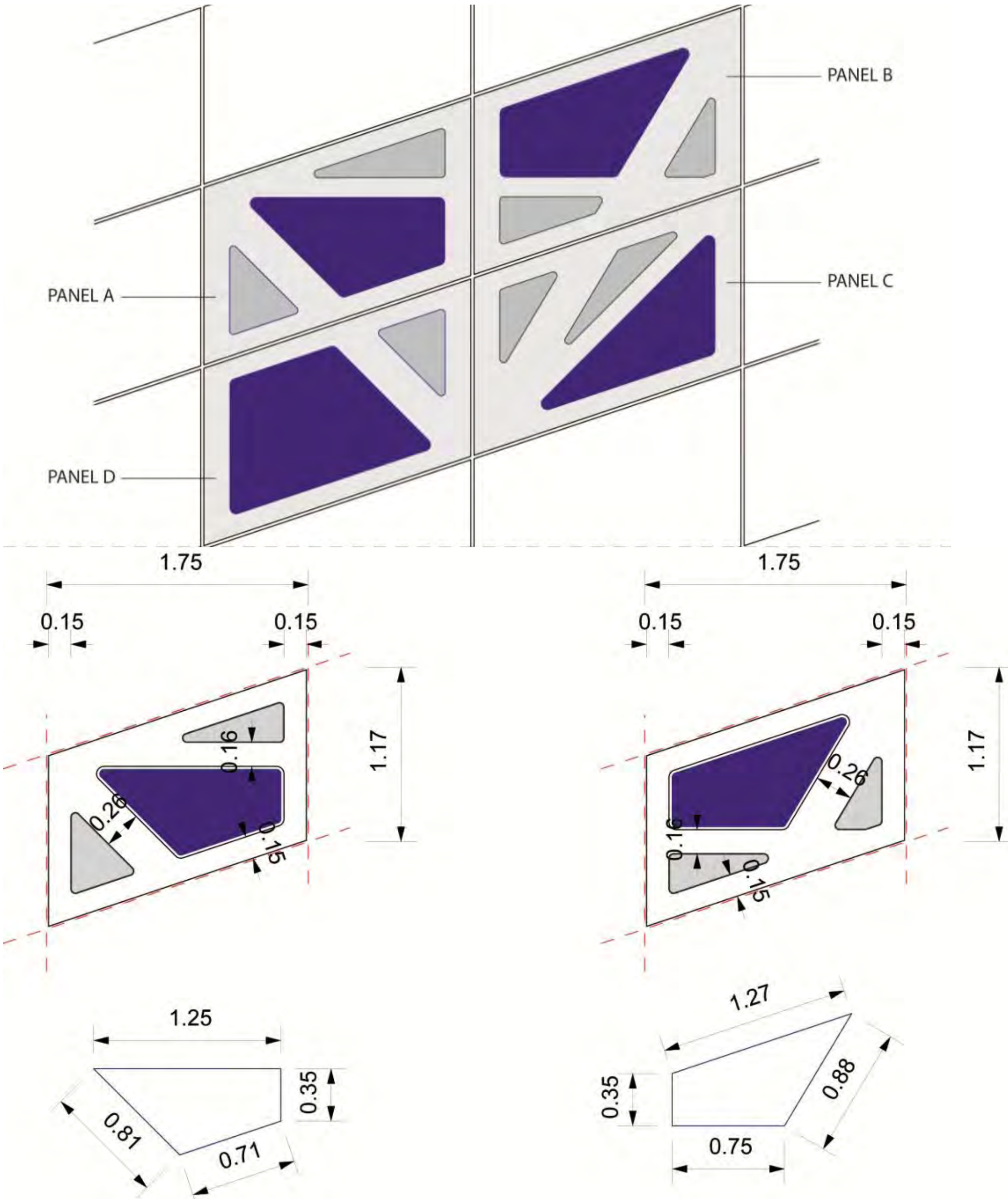

Figure 13: The typical panels and dimensions were carefully coordinated with the design intent and technical requirements. Image © Zaha Hadid Architects.

Manual checking was also required to ensure rooms on the interior of the project had sufficient window openings. This was done entirely in the 3D model, with a handover of the 3D model to the facades contractor at the tender stage. The 3D model established the design intent including panelization of GRC and the window locations. No 2D drawings were produced of each unfolded elevation as the setting out was completely in the 3D model. This allowed the most efficient and logical coordination of the design intent. The contractor was able to take the architect's tender 3D model and continue developing the surfaces directly in 3D, without having to remodel the entire facades from 2D.

Figure 14: A typical rendering of the KAPSARC facades design intent. Image © Zaha Hadid Architects.

An ongoing check to verify the window penetrations location from the interior of the building guided the overall aesthetic of the pattern. The contractor frequently sends 3D models for review which are then compared with the original 3D model to verify design intent.

CONCLUSION

Many factors influence the development of facades; this is complicated when factors such as high-performance requirements in extreme climates and complex geometries are aspirations of the project. In the case of KAPSARC, careful investigation of materials, technical requirements, and issues such as procurement and sustainability was undertaken from an early stage in the design development. Additionally, constant coordination was required as the design progressed to verify all requirements were met. This coordination through the process is a way of ensuring that the architectural design intent was achievable and ultimately constructible.

Figure 15: Images of the KAPSARC facades mockup from February 2010. Image © Zaha Hadid Architects.

[i] http://www.saudiaramco.com/en/home.html#top
[ii] http://kapsarc.org/