

FROM VERNACULAR TO PERSONALISED AND SUSTAINABLE

The value of additively manufactured window screens in Middle Eastern dwellings

NEHAL ALMERBATI, PETER FORD, AHMAD TAKI, and LIONEL DEAN

*De Montfort University, Leicester, United Kingdom
{p12046192, pbford, ahtaki, ldean}@dmu.ac.uk*

Abstract. The social and environmental role of closed oriental balconies (Mashrabiya) remains a significant vernacular aspect of Middle Eastern architecture. However, changes in architectural style, social needs, and the high manufacturing cost of Mashrabiya materials and techniques, Bahraini houses lost their very distinctive window veils. The research aims to validate a new Mashrabiya product for 21st century Bahraini houses using new manufacturing technologies. Additive Manufacturing (AM) is now at the heart of evolutionary technologies. Contextual information drawn from relevant theory, ethnography and practice is used to form a methodological framework for the new AM Mashrabiya. Additionally, interviews with architects, manufacturers and residents are the methods used to define a new AM Mashrabiya prototype that is then functionally and economically compared to other manufacturing techniques. Prototypes of new AM screens are developed. The main results set boundaries for the viability of AM to produce Mashrabiya and promote a sustainable way of reviving their use within Middle Eastern dwellings.

Keywords. Mashrabiya, additive manufacturing, innovative construction, personalised products.

1. Introduction

It is possible to use the traditional (vernacular) architectural elements of the Middle East for problem-solving design solutions in present-day architecture. The potential for achieving these solutions lies in the effective

combination of the design concepts of the traditional elements with new materials and technologies.

A Mashrabiya is an architectural oriental wood lattice screen or veil (Kenzari and Elshestay, 2003) and was one of the interesting vernacular elements noted by Fathy (1986), cited in Gelil (2006). Furthermore, Sidawi's (2012) study suggests that Mashrabiya is an effective screen element for hot-arid climates; Bahrain has a climate of this type.

Presently, designers and architects use contemporary patterns to reproduce Mashrabiya elements within their building forms, facades and even furniture (Benedetti et al, 2010), and a study carried out by Lim et al. (2012) suggests that it is possible to use Additive Manufacturing (AM) for the reproduction of architectural elements.

AM is defined as the process of solidifying liquid or powder using a binding agent or a melting laser, and can save time and transportation costs associated with importing primary materials if locally-sourced materials are available. AM allows for the three-dimensional production of objects or elements from models or from computer-controlled additive processes (Jon and Nathan, 2010). Also, the advantages of AM include enabling flexible shapes, mass customisation and affordability (Wittbrodt et al, 2013). Thus, this research intends to explore the use of AM methods in the production of Mashrabiya as a sustainable traditional element of 21st century dwellings in Bahrain.

2. Mashrabiya Contexts

It is very important to understand the structure as well as the function of this window screen. The following summarises the literature surrounding its past as well as the current and future possible contexts of a possible Mashrabiya revival using current manufacturing technologies.

2.1. HISTORICAL CONTEXT

Various researchers relate the name and definition of Mashrabiya to its function as a passively cooled space for storing clay water pots. The name is therefore derived from the Arabic verb '*shareba*' that means 'to drink'.

From a structural point of view, a Mashrabiya is a wooden lattice screen, more like a closed balcony, that projects outside the window for around 30cm or so. It is a shading device that absorbs daytime humidity and releases it at night.

The Mashrabiya also serves the important Islamic cultural and social value of privacy as it functions as an architectural veil. Since there is no definite date of origin for the Mashrabiya in Islamic history, some researchers claim

that it is related to Persian architecture. Closed window screens as well as wind towers were vernacular and sustainable solutions developed by ancient Persian builders. Various types of evidence showing the use of wind towers and Mashrabiya can be found in the traditional architecture of the Middle East, especially in Bahrain and the United Arab Emirates.

The small screen openings, whether made of fine-turned wood or shading louvers, allow segregated females to view the exterior world from inside without being exposed to the gaze of outside men. If communication is required, most Mashrabiya, especially Egyptian ones, have smaller windows that can be opened upwards. Gender segregation and veiling is a core value of the Islamic religion that made the use of Mashrabiya quite popular through history, especially during the Islamic Ottoman era and continues nowadays in various Arab regions. Mashrabiya are known under different names, such as *Shanashel* in Iraq, *Mushabak* in Iran, *Roshan* in Saudi Arabia and *Aggasi* in Bahrain, as noted by Almurahhem (2009) and Ben-Hamouh (2004).

Aesthetically speaking, the screen surface of Mashrabiya allowed Muslim craftsmen to show their decorative skills. As the use of figural shapes are forbidden in Islamic ornamentation, Muslims learned to use geometrical and abstract floral patterns. Not only did Muslims produce intelligent and complex mathematically-based ornamentation, they encoded it with meaning according to religious design guidelines. For example, the repetition of unified geometrical elements and shapes represents the infinity of God. Furthermore, worshiping through remembrance was signified through incorporating calligraphy or words that recall certain prayers or promote good manners.

The local materials and craftsman skills in Bahrain and the Middle East have strongly influenced Mashrabiya construction and made it unique to its region. When solid wood was not available as a local source, Mashrabiya were sometimes made of gypsum clay. As gypsum has a porous character, this was highly suitable for humid regions. However, the limitations and character of the ornamentation were very different to the ornamentation made out of wood.

The economic status of the household owner also governed the shape and material of the Mashrabiya. This led to the use of a cheaper type of wood and to louvers that were produced through simple construction. If both the available materials and craftsmen were not of a high standard, then wealthy house owners used to import Mashrabiya and this resulted in added costs which made them more unique and valuable yet also caused their alienation in later years.

2.2. CURRENT CONTEXT

Readers researching the aesthetic design and environmental factors as well as the cultural identity that surround Mashrabiya can easily note the reasons behind the modern interpretation of the Mashrabiya concept from several architectural, interior design and even artistic pieces of work.

In architecture, the environmental value of Mashrabiya was a defining concept. Producing an architectural envelope that can respond to daylight and the direction of the sun were the aims of the Albahar tower project by Aedas (2012) and the Oxygen Villa (2012) designed by Egyptian studio house. An earlier pioneering invention in the field was Jean Nouvel's Arab Cultural Institute design in France (1987). The idea of creating Mashrabiya windows that responded to sunlight like a camera lens aperture was groundbreaking although it was unfortunately subject to mechanical failure a few years later. The modern smart adaptive skin of the Albahar tower project wins the contest between intelligent Mashrabiya; it uses specialized programming methods and thermal actuators that open up the Mashrabiya-like facade like an origami fold. The verity of opening to provide sun shade were transformed as a structural membrane by both 109 Architects in their Saint Joseph University (2011) in Lebanon, King Abdulla university for science and Technology (2012). The local brick made Pattern House in Iran (2012) represents the combination of Mashrabiya-like structure made of local available materials and craftsman skills transformed on an architectural scale. The third interpretation of Mashrabiya in the architectural context relies on its shape, which recalls Islamic identity and cultural values. Excellent examples can be seen in the Masdar sustainable city (2010) and the GRC Mashrabiya units designed by Foster and Partners; further examples of the veiling for privacy can be seen in slide-S's (2011) proposals as well as the Mashrabiya House of Palestine (2011).

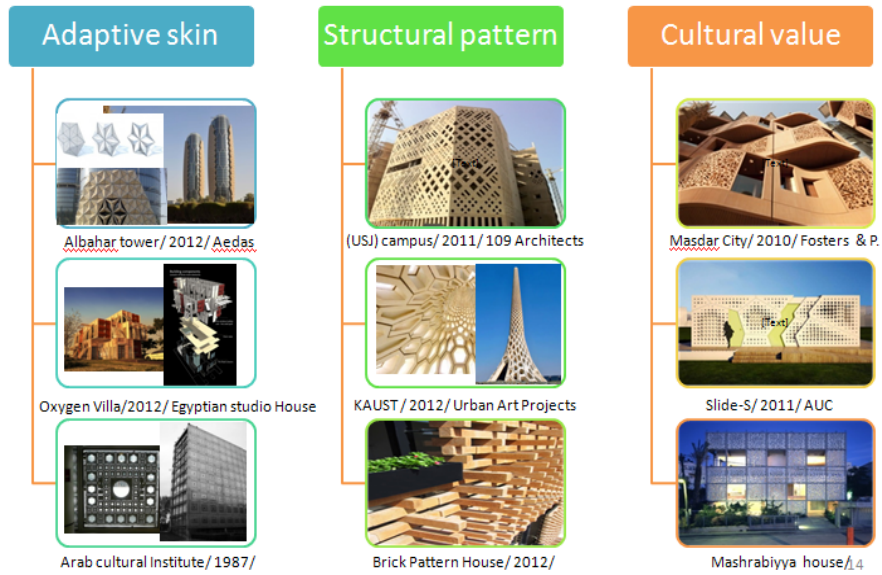


Figure 1 – Mashrabiya in modern architectural project context

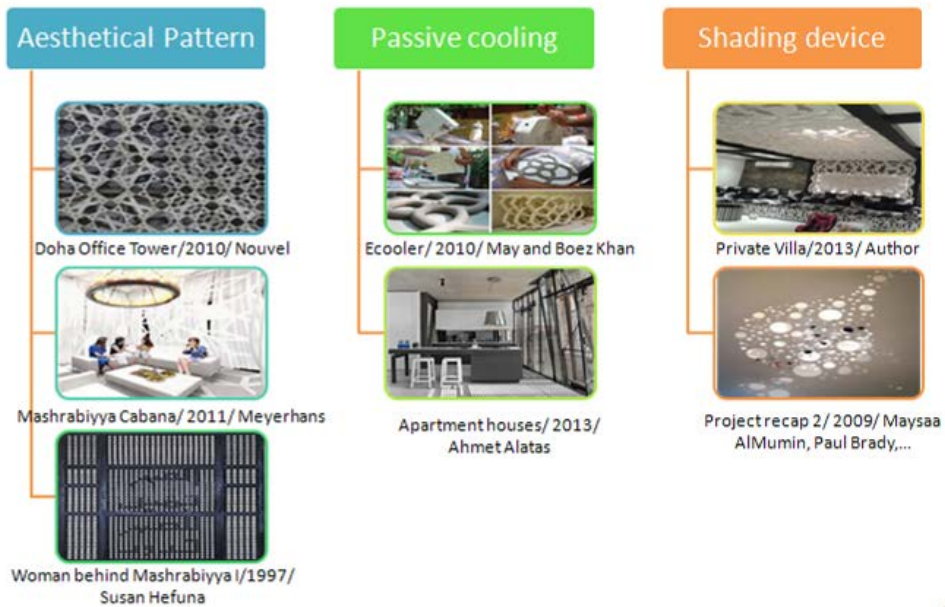


Figure 2 – Mashrabiya context within interior design

Interior design spaces have also been influenced by Mashrabiyas. Figure 2 displays the different interior effects of the researched element. The basic passive cooling function of the shading device is integrated with the beauty of the play of shade and shadows of its openings. Different new manufacturing techniques are being utilized, as seen in the CNC project recap 2 screen (2009) or the clay screen, entitled E-cooler (2010), that utilises water to perform a passive cooling effect like an old clay water jar. A distinguishing feature is the incorporation of writing, as introduced by Suzan Hefuna (1997), on artistic Mashrabiyas; this promotes dialogue between languages.

As a product, the Mashrabiya construction and its screen treatment has been used in furniture design, where it can be combined with calligraphy as well as light. Figure 3 displays the recent morphing of the concept and its treatment by both regional and international designers.

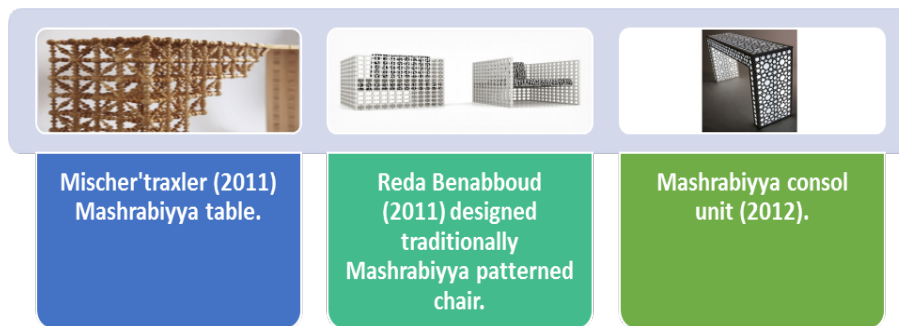


Figure 1 - Furniture inspired by Mashrabiya

2.3. MASHRABIYA MANUFACTURING METHODS AND 'AM'

To aesthetically enhance the thermal performance of windows and facades, several researchers resorted to using Mashrabiyas. Almost all used either local manufacturing techniques or adopted regional trends. Gelil's (2006) proposal relied on combining the design guidelines of the Japanese window treatment entitled Machiya-goshi with local Egyptian fine wood carpentry. The final product can be considered a simple, flexible and affordable screen that would best serve Cairo's new social and economic standards. However, a disadvantage of her design is its extreme simplicity; it lacks the aesthetic appearance of Islamic ornamentation seen in Traditional Egyptian Mashrabiyas. This raises the question of future user acceptance of the aesthetic appearance of this facade. Samuels (2011), on the other hand, proposes a more interesting design interpretation of the traditional Mashrabiya using Computer Numerically Controlled Milling (CNC) and Ceramic Injection

Moulding (CIM). His awareness of new manufacturing technologies has helped him to propose not only aesthetically appealing contemporary design solutions but thermally efficient ones for hot and arid Australian buildings. Samuels' material selection and manufacturing method can be considered successful compared to Bendettie et al's (2010) hardwood and softwood Mashrabiya experiment. The latter experiment conducted a comparison of the thermal performance of local and imported wood in a new proposed Mashrabiya for Italy. Their research method, programme simulation and real life fixing and testing of a manufactured new Mashrabiya set in motion a scientific approach to the design of this product.

Gelil (2006), Samuels (2011) and Benedetti et al (2010) responded to and relied on Hassan Fathy's (1986) guidelines, who recommended the use of affordable materials, and to produce a simple Mashrabiya construction that is similar to that of the affordable Egyptian Sheesh or wooden louvers. His intention was to revive a cost effective production of Mashrabiya, regardless of the skilled craftsman base needed, as it would serve the regional environmental and social context.

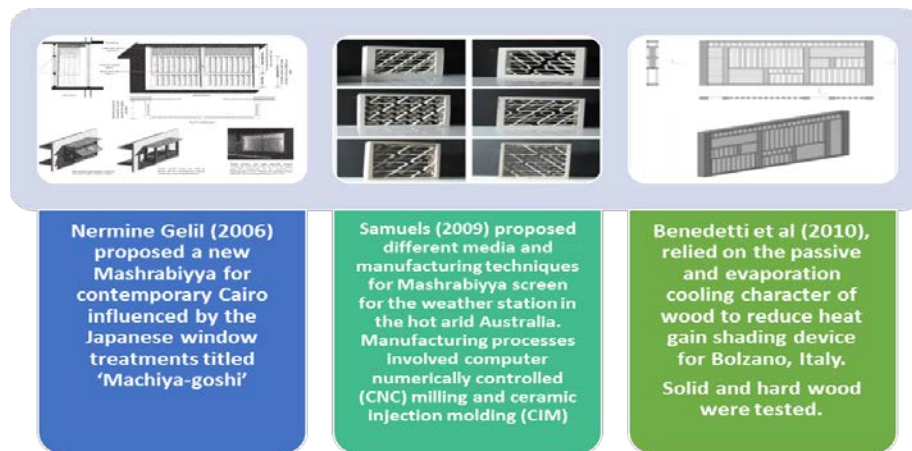


Figure 4 – Peer-reviewed new manufactured Mashrabiya samples

Looking at the various manufacturing methods in the market now, Mashrabiya's are still expensive to build and replicate. Nevertheless, Postler and Ferguson, a UK-based design company and the conceptualisers of the Microclimates project proposal, were pioneers in the field. In its outstanding Mashrabiya-based proposal, the company proposed using additive manufacturing or 3D printing as a substitute for the intensive tooling needed and to free the design from any milling constraints. Their final sand products for

public space usage were based on a three-dimensional interpretation of a Mashrabiya latticework design. The Microclimates to be printed by the D-shape company were to be built from clay with a complex internal structure. The large internal surface area is claimed to efficiently condition the air passing through it using an evaporative cooling character, when water is fed from above to this porous sand structure.

The Microclimates proposal bridges the gap between tool-free Mashrabiya and that of an architectural and cultural product that can respond to users' intentions and design preferences. Postler and Ferguson have hinted that AM Mashrabiya have never been produced before or researched; this paper aims to contribute to the knowledge through examining the affordability and design validity of AM-produced Mashrabiya.

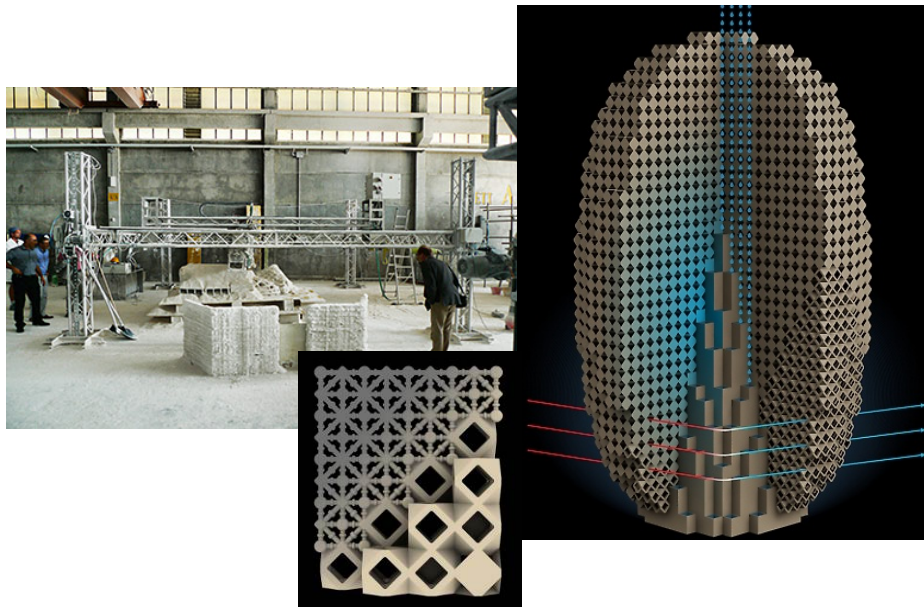


Figure 5 – The giant 6m bed D-shape printed (left) and the Microclimates (right)

3. Methods

To analyse the defining factors for the Mashrabiya contexts presented above, this research paper uses a mixed method approach that measures the (SAFE) values of using new Additive Manufacturing (AM) to produce such screen products. SAFE values refer to the Social drivers for Mashrabiya production and their use as an architectural gender veil, a focus on the Aesthetic and affordability factors of the window screen, their Functionality beyond a facade treatment and as a cultural identity metaphor, and lastly as an Environmental

and Economic measure for the new AM Mashrabiya in the Bahraini market and its climate conditions.

3.1. CASE STUDIES

Case studies from the literature on different projects that utilise Mashrabiya were considered, with a focus on examples within Bahrain and the Middle East.

3.2. INTERVIEWS AND QUESTIONNAIRE

The fair sample size of the representative of the population under investigation was calculated to give accuracy of about 90%, with 193 respondents being selected from the Bahrain population. Along with residents, around 40% of the major local manufacturers were interviewed.

- **Interviews with local and regional manufacturers:** To assess the current market and the cost of producing Mashrabiya using available materials and conventional techniques versus using additive manufacturing.
- **Questionnaire targeting both local and foreign residents:** To measure the SAFE value of current window screens and the factors involved in their design and new development.

3.3. PRODUCT PROTOTYPE AND FEASIBILITY STUDY

- **A small-scale AM Mashrabiya test model:** Used to conduct a feasibility study on different local and global AM manufacturers, with the results being compared to the price of the given design if conducted using local GRC or wood techniques. Later, the new AM Mashrabiya model produced would be assessed based on the feedback from an evaluation exercise completed by a Bahraini local, architects and a manufacturer focus group.
- **Feasibility study:** The researcher has compared and analysed the cost of a one metre by one metre Mashrabiya screen produced using local Bahraini manufacturing techniques compared to the cost of using AM sand screens.

4. Results

Since this paper is reporting on research in progress, the results discussed here form a summary of stage one of the methods adopted and detailed in section 3.

4.1. ABANDONED BALCONIES AGAINST STANDARD WINDOWS

An examination of the housing project trends over the last decade in Bahrain shows the role of abandoned exposed balconies that have been copied from Western Architecture. In Bahrain and many other Middle East countries, factors like the hot and humid climate as well as the social and religious attention given towards visual privacy and veiled openings helped foster the inward orientation of activities within the household.

Interviews with officials from the Bahrain Ministry of Housing showed that less importance is given to closed balconies in terms of their passive cooling effect and more towards the traditional touch they add to housing project facades that are still desirable locally.

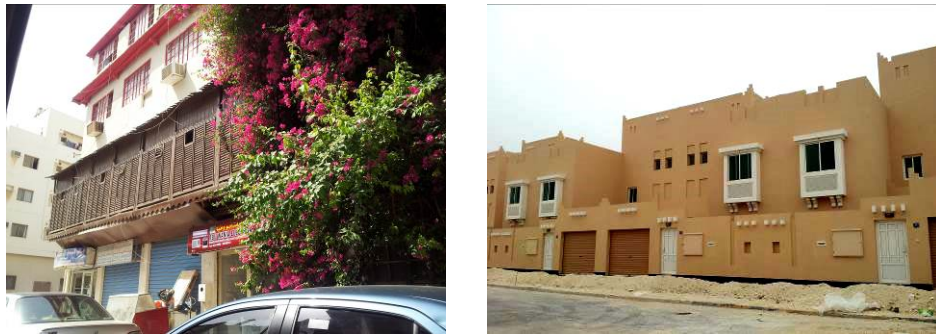


Figure 6 - The changing role of closed balconies in Bahrain from 1950 (left) to 2014 social houses (right). Source: Author

4.2. COST OF AM SCREENS AGAINST LOCALLY PRODUCED SCREENS

An ongoing feasibility study conducted in 2013-2014 on the current manufacturing costs of Mashrabiya in Bahrain is still ongoing. The cost of a one metre by one metre Mashrabiya product produced from local materials and techniques was investigated.

The average cost of a one metre by one metre Mashrabiya if made out of wood was calculated. Several types of wood were investigated; in view of the fact that the product will be fixed outside, solid wood like teak is therefore highly recommended.

However, since teak is an imported wood it has a very high cost and this is noticeable compared to other cheaper types of wood available in the Bahrain market. Other substitute materials can be used to respond to the privacy function of Mashrabiya. GRC molds, gypsum cut boards, or even aluminum louvers (Karkaris) are considered a much more affordable and durable op-

tion. The cost of the other materials is in the range of \$400. However, these other materials lack the flexibility and ornamental capabilities of wood. The average cost of a teak Mashrabiya is about \$2788, which is almost four times the price of ordinary GRC or marble and granite molded products.

4.3. NEW INVITABLE (SAFE) WINDOW SHADING SOLUTION

The survey conducted in Bahrain in May 2014 gathered information from 193 respondents from different dwelling types, ranging from private housing to social ones and from different types of accommodation with 3 to 8 bedrooms.

The majority (about 58%) of respondents considered visual privacy as the main factor that restricts the selection of window shading treatment, while the function of the shading device was viewed as the second most important factor, selected by almost 14% of the sample. Much closer percentage was the importance given to the aesthetic look and beauty of the shading device and its influence on the exterior image of the building. Not much consideration was given to the cost of the product and its maintenance cost, with only 8.2% of the sample considering it. This contradicts the opinion of an official from the Ministry of Housing who described it as the most influential factor that restricts the use of wooden Mashrabiya in housing projects around Bahrain.

Environmental efficiency was the least considered factor by Bahraini locals and residents, with 5.18% of the sample being influenced by this factor. This shows the limited awareness of the importance of sustainable materials and the need for passive cooling. This is strongly linked to the widespread use of air conditioned spaces in Bahraini houses and the low electricity power rates in Bahrain in particular and the Gulf region in general.

Moreover, 54% of the sample preferred personalised window designs, including Mashrabiya and screens with geometrical shapes over standard window treatments. Moreover data showed that there was a close proximity for the consideration of window treatments as an essential value to building cost and that of it as an added value or a complementary one to the building summing cost.

In terms of cost, the majority of Bahraini locals and residents stated that they would be prepared to pay less than \$663 for a window treatment, which is almost 25% of the cost of a solid wood Mashrabiya. This means that Mashrabiya are currently a choice just for the elite members of society. However, the current manufacturing techniques in the Bahrain market do not support elaborate or personalised designs, which is an advantage that can be

addressed and pioneered if additive manufacturing is used to construct these architectural facade elements.

On the other hand, unfortunately additive manufacturing is not yet a widely developed market in the Middle East. However, as the global technology and material becomes more enhanced AM will become more affordable for personalised products, even on an architectural scale. This was mentioned by the pioneering German, Voxeljet, who now can produce up to four metre by four metre sand AM structures that can be used as architectural window screens and Mashrabiya at a cost that may currently exceed \$4000.

6. Conclusion

To conclude, the results of this research firstly indicate that the production of an AM Mashrabiya model (screen element) is viable and would be a pioneering innovation in Bahrain and the Middle East region, since personalisation and skilled craftsman-free products are admired.

Secondly, adopting sand screens in sustainable architecture can raise awareness of the potential of using AM for the production of a sustainable architectural veil element and much more. Moreover, this research is an initial step towards shaping a framework so that AM can be used to produce cost-effective AM Mashrabiya in Bahrain within the coming 10 to 20 years.

References

- Almurahhem, F. M. 2009, Behind the Roshan. PhD thesis, Brighton: University of Brighton.
- Benedetti, C., Baratieri, M., and Leone, G. 2010, Wood technology for passive cooling Retrieved from: <http://www.ewpa.com/Archive/2010/june/Paper_386.pdf>. (Accessed 01/08/2013)
- Ben-Hamouche, M. 2013, The corners law: Leftover spaces versus sustainability in Arab Gulf cities: the case of Bahrain. *Urban Design International*, **18**(2), pp. 114–130.
- Gelil, N. A. 2006, A new Mashrabiya for contemporary Cairo: *Integrating traditional latticework from Islamic and Japanese cultures*, **1870**(May), 37–44.
- Jon, E. and Nathan, S. 2010, The rise of additive manufacturing. *The Engineer*. Retrieved from: <<http://www.theengineer.co.uk>> (Accessed 07/01/2014)
- Kenzari, B. and Elshestawy, Y. 2003, The ambiguous veil: On transparency, the Mashrabiya, and architecture. *Journal of Architectural Education*, **56**(4), pp. 17–25.
- Lim, S., Buswell, R. A., Le, T. T., Austin, S. A., Gibb, A. G. F., and Thorpe, T. 2012, Developments in construction-scale additive manufacturing processes. *Journal of Automation in Construction*, **21**, pp. 262–268.
- Samuels, W. 2011, *Performance and Permeability: An Investigation of the Mashrabiya for Use within the Gibson Desert*. New Zealand: Victoria University of Wellington
- Sidawi, B. 2012, A conceptual analytical model of the vocabulary of architecture. *Emirates Journal for Engineering Research*, **17**(1), 47–56.
- Wittbrodt, B. T., Glover, A. G., Laureto, J., Anzalone, G. C., Oppliger, D., Irwin, J. L., and Pearce, J. M. 2013, Life-cycle economic analysis of distributed manufacturing with open-source 3-D printers. *Mechatronics* **23**(6), pp. 713–723