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STUDY AND COMPARISON ARCH AT FRAMEWORK MODERN MATERIALS-CASE STUDY: IRAN

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ABSTRACT

With the shaping of novel ideas and trends in architecture, the traditional use of arched structures and forms is gradually fading away and being forgotten. This is while today the advancement of technology and the emergence of a wide range of innovations as well as the utilization of superb creativity have resolved many issues that were generally associated with arch shaped structures, whereby this particular type of structure has attracted attention and has gained importance in different ways. For instance, nowadays arch is used along with other kinds of novel innovations such as truss and space structures through the application of new materials like tent-like, membrane and composite structures. Rapid global progress in the domain of architecture and utilization of new technologies and revolutionary structures necessitates more attention and research on this field in our country. In this study, first existing research literatures on arch shaped structures have been reviewed critically and then considerations have been granted to novel compositions of this structure and accordingly it is hoped that the conclusions put forth by this research are considered in the educational and administrative sectors of the country.

Keywords: Arch, novel architecture, composition, creative spatial structures

INTRODUCTION

Natural features of construction materials and the manner by which they are used play a determining role in defining the form and the space of the architecture.

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So much so that it can be said confidently that forms play a unique role in the formation of location merely through construction materials. In the old days, long before the advent of new techniques, the materials being used would specify the intended form and would constitute the formation of the space of the architecture. According to August Pere, Magnificence is an honesty which yield a beautiful structure." By honesty he means defining the form based on construction materials and using them appropriately in construction projects.

Every material has its own definite potentials and capabilities and can be formed in certain ways by reliance on such particularities. This basically translates into the fact that each material requires a specific type of formation and can be used in special volumetric and spatial forms, thereby affecting the overall appearance of architecture. For example, the form of a wall opening is subject to the materials which have been used in constructing that wall.

An opening in a brick wall requires an arch while for openings in steel and glass walls slanted openings seem more suitable. It is precisely due to such an effect that it is virtually impossible to imagine the Eiffel Tower to be made of bricks and the Le Corbusier Cathedral to be made of glass and steel (Mea'amarian, 1988).

Steel truss bridge- **Image** 1‹
(Durkee, May 24, 1999)

Innovative materials being used in new structures display a mixture of tension and compression. Gradually and overtime, the utilization of an arch within a structure as an element to withstand the load of a building or its covering has found new applications. One of the best examples is bridge construction which experienced a revolutionary transformation with the advent of new materials like steel and steel cables. In fact, the capability of steel to properly mix with concrete has led to new designs in arches and a significant increase in ability to make them longer in constructions (Aghajani Namin, June, 2012). A good example is illustrated by contrasting pictures 1 and 2 both of which have been taken from the same location. In Picture 1, a bridge construction with multiple openings made in 1900 of construction materials and stones similar to ancient Roman aqua duct structures can be observed. In comparison Picture 2, shows a bridge constructed on the same river with a single, wide spread arch using novel materials which has replaced multiple smaller openings

due to high tolerance of steel laced concrete (Pacific Earthquake Engineering Research Center, 2011). Moreover, other materials such as hot and coldrolled steel, petroleum by-products (PVC, polypropylene, etc.) have played an extensive role in construction of temporary structures.

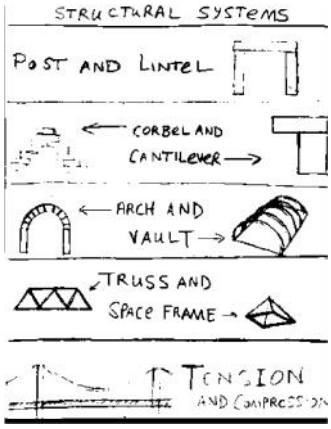
Image Shmarh3-Paul Fursteuland, on the River Sitter,

Figure 2 multi-span railway -Pl Building, on the River Sitter

With full regards to this matter and the general view of the current study on up-to-date technology, first, we will attempt to study and compare some examples of innovative arch shaped structures in which modern construction materials have been used and point out their strengths and weaknesses. And next, we will review the existing capacities and the restrictions in the Country of Iran by carefully considering the prevailing conditions and will make an effort to study all relevant opportunities and challenges facing every single one of these structures and finally, we will introduce an arched structure which is appropriate and proportional to the overall conditions across the country.

Arch Form

After years of migrations and living in mountains and caves, early humans began to build refuges for themselves. Initially, most of such structures were built by stacking pieces of stones atop of each other until the desired height was reached. However, because of limitations of these structures, gradually stones were placed on top of each other step by step moving upwards forming the first stone huts for community living. Later on with the discovery of limestone and constitution of new mortars, the principles of constructing the earliest arch began to materialize (Zamrshidi, 1988).



TtsvyrShmarh5-Askys·hayy appearanceofthearc, writer

Image Shmarh4-sample of Nrkhay caused by the drift

Ghiasoldin Jamshid Kashani (circa 790-832) defined arch as: An arch is a curved object whose mouth opening is larger than its depth. The balance of arch is closely related to foundation and torque being exerted by the load which is transferred onto the shoulders of the arch itself. Implementation of this technique then was considered to be ahead of its time. The history of using arches dates back to thousands of years BC and the application of this construction element was quite common in Mesopotamia as far back as three thousand years ago (Gholam Hossein Mea'amarian, 1990).

Arch may be defined as a structure whose ability to withstand the imposed vertical loads depends on the vertical component of the reaction of its resting bases both of which tend to act towards the center part of the arch. Since the ancient times, engineers and builders have constantly tried to achieve compressive forces without the parameter of eccentricity. Such attempts can readily be seen in historical constructions with arches and domes. However, because of insufficient experience and low knowledge of construction material properties, arch was always thought of as a part of the overall mixture of building materials which can tolerate extreme compression whose end result are casings of tombs, mosques and large spaces throughout the world and Iran.

When building materials possessing bending strength were expensive and because of their high susceptibility to climatic factors, arch was a type of structure which would commonly be used to cover even the smallest openings. Both Roman and Romanesque architectures are known by their semi-circular arches. Gothic arches with rather high leaps and wall with supports to prevent propulsion forces are indicative of excellence in designing the architecture of gothic churches and cathedrals (Salvadori, 2003).

In recent years, a great number of studies have been carried out on the ability of building materials and the emergence of new arch shaped structures. Considering the limited availability of building materials, such formations at their time could only withstand compression forces and noting the fact that materials which could tolerate stretching and handle the force of flexural bearing were non-existent then arch shaped formscan be labelled as merely unique (Yousefpoor, 2004). Overtime, as technology of processing fine construction materials developed and more discoveries and inventions were made, materials like steel, concrete, wood, wood by-products, etc. have instigated an incredible transformation of building shapes and forms, thereby causing brick domes - considered as feats of architectural engineering at their time - to find new applications.

It was through sheer creation of new construction materials highly resistant to bending that significant accomplishments in building constructions were made possible and semi-circled Roman arches up to 30 meters and medieval stone bridges with arches up to 55 meters high were constructed. As of today, the New River Gorge located in West Virginia in the United States has the largest steel arch which covers an area of 518 meters. The largest arch made of steel laced concrete is in Krk Bridge in the former Yugoslavia with an opening of 390 meters. A mix of truss arches with half-arched crest conventions linked together with truss cover an opening with an area of 550 meters in the Quebec Bridge. Up to the present no other structural element for covering large distances has been used as much as an arch (Salvadori, 2003).

Reviewing Various Arch Shaped Formations based on Building Materials

Arch Shaped Structures using Building Materials

An arch shaped structure is one which utilizes individual units as layers in the construction of the arch. Mortar is used in between these layers and usually other materials like bricks, stones, marble, granite, travertine, limestone, cement blocks, cast stone, glass blocks, a coating of plaster and cement are used in construction of arches.

Sometimes arch shaped structure is built without the use of any mortar. This type of construction is the most primitive manner of in building a structure in which pieces of stones or blocks are placed next to each other in an orderly manner. Accordingly, these structures have a low tolerance and are only applied in temporary, worthless and decorative arches (Millias, 2005).

Building structures are considered to be the most practical and the most traditional methods of constructing arches in the world used for making passages, bridges, walls and similar cases which have had applicability since the ancient times.

The largest arched bridge in the world made of building materials is the Pont de la Liberation Bridge (1919) in France with an opening of 96 meters.

Table 1. Arch Shaped Structures- Materials

Description	**Arch Shaped Structures- Materials**
● Due to the application of local materials, the construction of such structures is quite cost-effective and they often do not require a painting coat or a casing. ● Advanced technology is not needed in these constructions and the can be built in far off places with the least amount of facilities. ● Construction materials like brick and cement increase the insulation properties of the building. ● Construction materials used in buildings have a higher rate of durability in comparison to wooden buildings and as result have a longer life span (500 years as opposed to 30 years).	**Advantages**
● Surface of building blocks deteriorates rapidly in extremely hot and humid climates. ● Building materials are heavey, hence a foundation is necessary for construction of these structures. ● Construction is not mechanized and has to be carried out by skilled builders and as result it is not cost efficient in places where labor is expensive. ● Due to their heavy weight and high density such structures are not resistant to earthquake and as result extensive building codes and restrictions have been set out for their construction. ● In order to retrofit these structures and make them resistant to earthquake, strong gusts and vertical and horizontal impact forces, vertical and horizontal cables must be used.	**Disadvantages**

Steel Arches

The application of metal in building an arches dates back to the construction of Coalbrookdale Bridge in England using cast iron which has an opening of 30 meters. Later on, other cast iron bridges were used with arched beams. Gradually, low carbon iron was used leading the

construction of I-shaped profiles. The invention of steel; however, with a tear away tension of 2,400 to 7,000 turned this metal into one of he most widely used building material in constructing arches. Invention of steel was soon followed by concrete and lacing it with steel rods initiated a revolution in methods being applied in building constructions. The use of this specific mix is so much in use today that one can hardly envision structures and buildings without the use of any steel (Golabchi, 2010). The largest arched bridge in the world with a height of 204 meters is in Dubai. The construction of this bridge begun in 2008 and the project is expected to be completed by 2015 at a cost of USD 817 million. The length of the bridge is one mile and its height is 670 feet (Theroux, 2008).

Table 2. Steel Arches

Description	**Steel Arches**
● Resistance and ability to take up forms: The pillars and beams of the lower floors of an arch can be constructed simultaneously and in less time. ● Possibility of industrialization (time efficiency): Reduction in construction of the skeleton of the structure leads to cost saving. ● Accuracy in execution: Entire pieces used in the metal frame can be inspected and controlled visually in pre and post-installation phases, whereby any defect which be noticed can be rectified instantly. This is not possible with a concrete skeleton because all meshes are covered in concrete. ● Capable of being disassembled: The skeleton and entire pieces can be disassembled at ant desired time and have them transferred to a new location and erect a new frame which in a way is a form of investment leading to cost cutting in the long run. Again, this is not possible with a concrete skeleton. ● Inflammable: Under normal conditions it will not be engulfed in flames.	**Advantages**
●Improper welding: All attachments of pieces in metal structures is done by welding and riveting. Improper welding due to work of an inexperienced welder, utilization of old equipment , lack of sufficient monitoring by the overseeing engineers, high cost of testing welding	**Disadvantages**

points, etc. are some of the most notable weaknesses in metal structures. ●Corrosion: Elements such as humidity, sulphates and industrial gases are extremely corrosive to metals, although the pace of corrosion can be slowed down by using paint or alloys like stainless steel. ●Rapid reduction in resistance when exposed to fire: Steel loses half of its capacity when exposed to temperatures of 316 to 649°C which causes the sudden crumbling of the steel structure. To solve this problem, physical coverings or fire extinguishing systems may be uses (Chen0weth & Jensen, 2005).	

Space Frames (Geodesic Domes)

Ever since the production of the first samples in early 20th century (1903) by Alexander Graham Bell, space like lattice structures have been used because of their light weight and resistance as well as the speed and ease of their implementation. Lattice structures are available in various forms and for different functions (Chilton, 2008). Geodesic dome is a globe structure which is capable of transferring loads through its linear parts which are arranged in a globe shaped dome onto its bases. Most of such structures are constructed from steel; although, use of aluminium is also quite wide spread. Other materials like wood, concrete and plastic are used as well (Chilton, 2008).

Due to the potentials of space like lattice structures, creation of various beautiful and intricate spaces is readily possible. Some popular forms to point out which are widely used for this types of structures include arches, domes, pyramids and unique shapes.

For arched shapes, the space like lattice structure is designed in such a manner so the interior and exterior of the structure has a circle shaped arch. This arched circle may be fully arched or semi-arched. Domes are usually used to transfer natural light into buildings and to act as roofing of large spaces such as stadiums without the use of any kind of mid-columns.

As far as general appearance of a structure is concerned, this type of architecture is divided into two separate groups, namely the semi-spherical and semi-oval. Moreover, the textures utilized are also separated into ten different kinds (ribbed, bulb, elevated, etc.).

Pyramidal forms are normally executed as complete or incomplete pyramids most of whose applications are in beautifying city spaces and instituting natural illumination for residential and commercial complexes. Also, as mentioned previously, space like lattice can be

transformed into any architectural form including wavy shapes, u-shapes, full sphere shapes, cylindrical shapes, saddle shapes, etc.

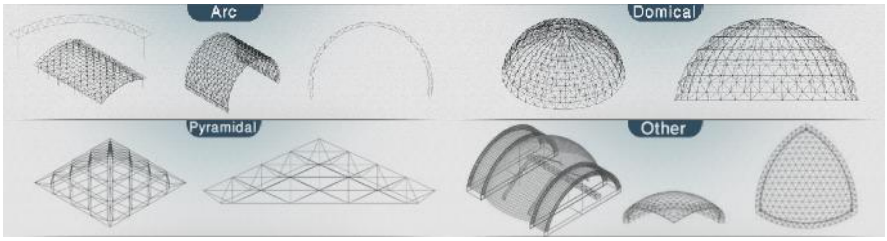


Figure6.3DtrussQvsaydownload: Chyltvn2009

Table 3. Space Frames

Description	Space Frames
●Proper distribution of load ●Easy installation in facilities ●High rate of resistance ●Modular components ●Freedom in selecting the best spot for bases ●Arranged geometry ●Ease and convenience in installing (Hibbler, 2005)	**Advantages**
●High costs and non-economic feasibility ●Complexity of geometry ●Time of installation ●Fire resistance	**Disadvantages**

In any case, it should be noted that since advantages far outweigh the disadvantages then the negatives under certain circumstances can be ignored.

Light Pre-Fabricated Structures – Structure Frame

A pre-fabricated arch shaped structure is one whose parts or components are manufactured outside of the site (usually in dimensions which can be readily installed) and then put together or installed at the site. The frame of this structure can be built in such a way that makes the implementation of a wide range of shapes possible for roofs and as result have the pillars or the columns join the crown of the frame or link them directly to another part or the truss or get these two points connected by using a curve part or member. Different sorts of couplings for the above-mentioned forms are possible (Den Hartog, 1987).

Since the parts or the members that are going to be used for roofing have to have a curved shape in the structure frame, their appropriate selection is of utmost importance. Box profiles

are considered to be some of the most suitable options for metal frames of LPS structures. The selection of these profiles particularly for heavy frames with large dimensions and size – keeping in mind the bi-axel bend of members (wind, earthquake, snow and frame weight in latitude direction and wind and earthquake in longitude direction) – facilitates improvements to make the structure much lighter (Gam-e-Abi Farda Company).

Furthermore, it is possible to select different methods of joining these two states together. However, past experiences along with the studies conducted so far indicate that the curved method of connection which draws the geometry of the roofing closer to an arch shape, aids greatly in the proper distribution and linkage of loads to the columns and eventually to the ground (Davoudpor, 2006).

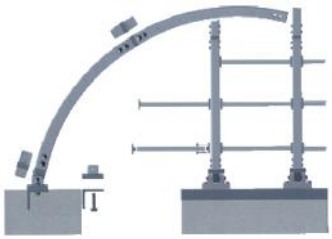


Image Shmarh7-Arch prefabricated steel, (Davoudpour, 2006)

Image Shmarh8-Arch prefabricated steel,

Table 4. Structure Frame

Description	**Structure Frame**
●Less execution time: one month ●Negligible human error in constructing ●Highly resistant to earthquake ●Relative beauty in appearance ●Light weight ●Causing less noise pollution during the construction phase ●Low rate of wasted construction materials ●Requires less work force and equipment ●Less turn over time for the investment from two years in the traditional method to five to six months ●Elimination of intricate connections	**Advantages**
● Requires skilled workers ●High cost ●Imposing restriction on number of floors which can be constructed (four floors)	**Disadvantages**

Concrete Arches

Concrete as a novel building material which is capable of being transformed into different shapes was introduced to the world of architecture in the 19th century. From the perspective of transformations which have occurred in the field of architecture, concrete structures express the history of modern architecture just the same way large steel structures or multi-floor buildings did (J. Ambrose, 2002).

In addition to simple building systems like concrete posts, more complex forms have been constructed with regular concrete or pre-fabricated concrete. Arches and domes are other building systems with large openings which are used in designing buildings. Pierre Luigi Nervi was the first architect to use these building systems in constructing airplane hangers and later on in construction of sport spaces. He also used concrete netted domes in some of these buildings.

Table 5. Concrete Arches

Description	**Concrete Arches**
●Capability of concrete structures to be formed into various shapes based on different geometries and various types of arch forms ●High rate of resistance of steel reinforced concrete which leads to high tolerance in handling loads ●Resistant to fire ●Possibility of pre-fabrication ●Non-corrosion of steel within the concrete due to environmental and climatic factors ●Resistant to bending because the effective composition of steel and concrete ●Suberb insulation properties against moisture and the transfer of noise, heat and moisture	**Advantages**
●Requires the provision of tension resistance in areas subject to tension ●Lengthy curing process ●Requires the right type of execution conditions and has limitations pertinent to temperature and moisture ●Larger dimensions and heavier weight compared to steel structures	**Disadvantages**

●Requires skilled workers ●Non-recyclable ●Highly fragile ●Corrosion can be caused by aggressive ions ●Extremely difficult to demolish and to make changes and to strengthen	

Membrane Structures

Membraneis one of the most available and widely used construction forms that are easily noticeable in our physical surroundings. From the stand point of geometry, these structures are able to divide a specific volume of space from other spaces and from the perspective of engineering they are considered to be some of the best structures. Numerous arched forms can be seen naturally such as in the skull and in eggs as well as many members which protect vital organs in living organisms. Furthermore, water and gas tanks, silos and arched dams as well as airplane fuselages and automobile and ship bodies have are made or manufactured based on this concept or type of structure (Zingoni, 2005).

From the geometric stance membranes are divided in two separate types, namely expandable and non-expandable. Cylindrical membranes fall into the expandable class while spherical membranes fall into the non-expandable one. As far as load tolerance and mechanical capacities go, non-expandable membranes are able to withstand extreme bends and twists. This is mainly because any exerting force is confronted with an opposing force of the membrane in reaction to expansion and changes in shape and form.

Improving the Performance of an Arch in Membrane Behavior

There are three main axes in membranes. One of the axes of this system is vertical to the membrane and the other two are tangent to spatial curves related to the main protraction of the curve. In addition to the rift forces and bend and twist anchors, the field of cortical forces are efficient in membrane systems.

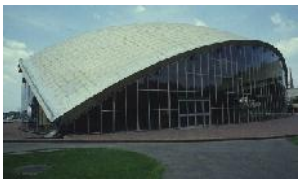
Static Penetration

One occurrence in arches is that any rifting force or bending anchor which affects a point on the object has far reaching penetration within that object while such impacts are only local on membrane forms. As we get farther away from the base or the area handling the brunt of the load or the area with geometric discontinuity, the effect of the inclination field diminishes significantly.

Load Transfer

Transfer of load in membrane structures is done either mechanically or through cortical forces and only in some special areas such as around connecting and discontinuity subject to concentration of loads and certain side conditions do the bend mechanism activate and transfer some of the external force being exerted. These types of force transfers place the membrane high on the list of forming evolution (Aghayere, 2008). For instance, coverage of a roof with an opening of about 40 meters requires a concrete membrane with a thickness of approximately five centimeters. The technology of concrete can be an appropriate solution for reaching arched formations because of two reasons which are resistance to compression and the capacity to take various shapes and forms.



ImageShmarh9-type skinArch, M., shells

Table 6. concrete structure

Description	**concrete structure**
●Reduction in usage of concrete as a construction material ●High resistance to storm and fire	**Advantages**
●Problems and difficulties of sealing concrete and subsequent water leakage ●Uniform construction results in compression impeding the air flow	**Disadvantages**

Wooden Arches

Wood has been utilized in arch shaped structures such as in the arc of arches and domes due to its tension resistance properties to solve the problem of running or sliding. The only quality which arches made of other materials have over wood is their resistance to fire and their durability.

Wooden arches cause less propulsion so they can be readily used over light weight walls. Although, the shape of the arch essentially correlates to the behaviour of the construction

materials being used, but this form is easily transferred to wooden structures, thereby making the construction of arched shapes much easier. Moreover, today innovations in the manufacture of industrial wood have eliminated many problems commonly associated with this material like the level of its resistance to fire consequently transforming wood into a more suitable construction material and an optimal choice for environmentalists. Some of the products of this class include glulam, composite, plywood, etc.

Table 7: Wooden Arches

Description	**Wooden Arches**
●Relatively high level of resistance ●Low level of density ●High level of conductivity ●Suitable resistance to impact forces, in general the more porous the wood the higher its impact tolerance ●Effect of air, oxygen and water on cellulose: Under normal temperatures, dry air has no effect on cellulose ●Oxidizing and alkali materials as well as diluted acids do not affect cellulose (Forootani, 2011)	**Advantages**
●Wood pests: Fungus, micro-organisms and insects ●Flammability of wood ●Changes in dimensions due to elements such as heat ●Low bending resistance: Wood can experience extreme changes arising from bends and twists and if the exerted force is higher than the bend tolerance, breakdown of texture can occur ●Effect of acids: Mineral and organic acids only affect cellulose if they are highly concentrated	**Disadvantages**

Wooden Space Frame Structures

Today natural forms and construction materials, namely wood and wood by-products are used in wooden space frame structures. Spatial wooden arches with joint connectors made of steel and attached wooden parts along with mechanisms of natural three dimensional load transfer are made of wood. The type of glue applied is usually laminated timber glue. Because of the light weight of these structures, the dead load is extremely small eliminating the need for too many columns and relevant parts making them ideal for larger size domes without any columns such as lecture halls, community halls, airplane hangers, etc. wooden domes and

arches transfer forces three dimensionally and their associated parts are capable of compression or tension performance. All wooden structures have the same modules which may be in the form of two dimensional trusses in some structures which are linked to one another in the third dimension. The most important part of wooden spatial structures is their connecting points between columns and the overhead structure. In these structures, entire connections are made of steel. Another noteworthy factor is the protection of a wooden structure against fire and boosting its resistant to insects and fungi growth which has experienced significant changes with novel technologies as of late, although somewhat costly (Faezipur, Amiri, Bayatkashkoli 2006). Timber glue is used more than any other wood by-product in uniform or consolidated construction of wooden spatial structures and in general all connectors are joint connectors made of steel. Designers should pay close attention to the arrangement of wood fibers since resistance of the wood is for the most part in the direction of its fibers. Timber glue is ideal for creating cross-section surfaces with rather large arches out of building parts; however, the most cost-efficient openings to use for covering purposes with arches made by timber glue are 15 to 60 meters for frames and 20 to 100 meters for arcs.

Figure 10. Hall Richmond Olympic Winter Sports Dome, Arch wood glue to follow the way of WWW.ARCHSPACE.COM

Description	**Wooden Space Frame Structures**
●Suitable for styling and highly resistant to earthquake ●Speed in constructing and quick return of investment ●Long life span of the structure ●Cutting down on wastage of construction materials ●Industrialization and an increase in QC at the factory ●Less polluting to the environment ●Increase in work safety ●Elegance and compatibility with different climatic conditions ●Reduction of negative effects of electromagnetism on humans	**Advantages**
●Does not change shape and does not return to the origin shape	**Disadvantages**

●Water and moisture can cause severe damage to wood ●Incendiary properties ●Non-resistant to insects and fungi ●Requires skilled workers ●High cost	

Introduction of the Background of the Study: Country of Iran

Iranian architecture has unique features which are considered to have special values as compared to the style of architecture in other counties. Some of these features are appropriate designing, precise and accurate calculations, the right form of casing or covering, compliance with technical and scientific issues in buildings, high ceiling porches, tall columns and finally various kinds of embellishments which although are simple, but at the same time are a symbolic representation of the magnificence of the Iranian architecture.

The use of arched forms in the Iranian architecture dates back to the Parthian period. In order to reach self-sufficiency and also in an attempt to apply only local building materials, the Parthians were not very keen on bringing in the required construction materials from far off distances like the Achaemenians did. This is why they formed the vaulted covers for large openings and quadrilateral surfaces which is looked upon as one of the most significant inventions in the history of architecture. Using arched and vaulted structures was quite common throughout the history of Iran and colossal structures such as Taq-i Kasara (Sassanid era) have been built based on this system which cannot be rivalled.

With the materialization of modernism in architecture in the current century, and the undeniable dominance of its accomplishments, and with full regards to the fact that Iran was not the birthplace of modern contemplation, exploiting modernism seemed inevitable. Thus, the encounter of modern thoughts with the system of intellect, customs and religion in Iran led to the unavoidable incorporation of modernism and tradition which began to take shape in Iran from the end of the reign of Mozaffar al-Din Shah (a king of the Qajar Dynasty) and continued over the next century resulting in new forms in the domain of architecture. These forms were presented in pre-modern, internationally modern, indigenous and even traditional Qajar and Reza Shah period architecture, but with the application of new technology. In more recent years, some different samples of post-modern style from historical to de-construction can be seen (Bani Masoud, 2010). Because of the climatic conditions prevailing in Iran, ancient Iranians had to utilize resistant and durable building materials and accordingly, gained

plenty of expertise in constructing buildings and structures and were able to reach the true meaning of the art of architecture quite rapidly (Pirnia, 2012). During the Qajar dynasty, changes in architecture materials being used were followed by transformation in the appearance of form and structure of buildings. Meanwhile, changes taking place in the field of industry and the necessity of new urban facilities, architects began to pay more attention to construction of certain buildings like railway stations, exhibit halls and manufacturing plants. Many architects of the time exploited the concepts of architectural designs seen in the post cards of European buildings which Qajar kings were bringing back to Iran from their trips to Europe. That is why an incorporation of ancient Iranian architecture and modern European architecture can readily be observed in structures of that period.

Image 13-silo cement = Semnan, Iran

Figure12.MiningChgharnbylArdekanI

Application of novel construction materials, particularly cement quickly became wide-spread among Iranian architects, engineers and master craftsmen. The use of new materials gained so much popularity that in 1934 and within only one year after the commissioning of the first cement plant in the country, many different uses for this construction material were improvised by architects such as in making statues, government and administrative buildings including the Kakh-e-Shahrbani (the Police Garrison).

Today, cement and steel in the form of metal frames, concrete frames and bearing walls reinforced with steel rods are being used in the construction of all buildings pursuant to regulatory technical specifications throughout Iran. Buildings entirely made of wood are used in moderate and humid climates mainly because of high level of humidity and even more important because of abundance of required resources of wood in such regions. However, a low percentage of all buildings are constructed by wood (Vayseh et al., 2009).

According to the statistics put forth by the International Statistical Institute in 2014, Iran has produced 14.97 million tons of steel which shows a six percent growth compared to the previous year (Iran Steel Association, 2014). Moreover, 75 million tons of cement was

produced in Iran in 2013, 65 million tons of which was used for domestic purposes (Iran Steel Association, 2014). Although, Iran has a large wood reserve, but currently most wood materials used in the residential sector are imported (Bayat Kashkooli, 2010) and the projected volume and amount for all wood related products show an increase for the following year. The total for import and export of wood and wood products in the next few years (2008 and on) is expected to reach over two hundred million dollars fourteen million dollars, respectively.

Since construction of most buildings in Iran is done with metal or concrete and non-reinforced masonry buildings have to be constructed pursuant to Earthquake Regulatory Memorandum 2800 of Iran, familiarity with advantages and disadvantages of buildings can entail some benefits for owners and engineers alike in decision making.

Assessment of Opportunities and Challenges of Studied Structures in the Country of Iran

Advantages

Considering the above-presented topics and discussions, opportunities of using novel arch shaped structures in the country can be divided in two separate domains:

The first domain is related to functional structures including arch shaped steel or concrete structures and geodesic domes which can be utilized for constructing large openings and covering large buildings like sports arenas, convention halls, etc. Furthermore, for constructing longer openings in bridges and to institute an optimal use of building materials, steel and concrete arches are excellent choices.

The second domain is related to the architectural symbols of the country. An arch is a structure which readily displays its behaviour. It imposes a high degree of visual effect and it possesses a unique beauty because its structural behavior is in total harmony with the nature of the structure. Accordingly, in order to promote and elevate the level of architecture in the country and to constitute urban symbols, arch forms and membrane structures offer the right solution.

The proper behavior of arch shaped and membrane structures makes them resistant to destructive natural forces such as earthquake and considering the fact that Iran is an earthquake prone country, this opportunity can be applied to promoting the quality and workmanship of construction throughout the country.

Because of the light weight of steel and wooden arches, they are ideal for restoration of existing historical buildings in the country or even to utilize them in creating innovative structures so as to bridge the gap between traditional architecture and architecture of Iran.

All arches made of steel, concrete and even wood may be pre-fabricated which offers benefits like reducing workshop costs, affecting an improvement in the quality of industrial parts, increasing efficiency and lowering production time which today are considered to be essential to construction projects taking place across the nation.

Among all types of structures, arch shaped structures have the highest rate of tolerance to the volume of construction materials. Hence, using less building materials can lead to higher degrees of tolerance and much larger openings which in itself is a giant step in the direction of the principles of sustainability and green architecture in the country.

Challenges

With full regards to the topics and discussions put forth in this study so far, arch shaped structures are generally used in buildings with high openings and as result are not suitable for smaller size buildings like residential and administrative offices which account for a large percentage of constructions in the country. Additionally, even if arches are used in smaller buildings, they can create serious impediment to performance of the building. Therefore, application of this particular type of structure is most certainly facing some limitations.

At the present, a specific regulatory memorandum on the method of designing arch shaped structures such as geodesic domes and membrane structures does not exist in the country of Iran. And the memorandums which do exist have special restrictions like specifications on the thickness of the structure which result in a decrease of efficiency and performance of these kinds of structures. Pre-fabrication of such structures in the country requires support and without an appropriate production line to manufacture the pre-fabricated materials, the possibility of exploiting the advantages of pre-fabricated arch shaped structures will not turn into reality. Moreover, the implementation of various arch shaped structures needs a process of precise and accurate designing and utilization of a skilled workforce as well as critical QC of connectors. These are some of the most crucial phases in executing an arch shaped structure. So, putting a team of skilled and seasoned craftsmen together is presently a serious challenge to execution of these kinds of structures in the country.

Prioritization in Selection of Arch Shaped Structures in the Country of Iran

After weighting and assessing the positive / negative criteria of different arch shaped structures and submitting this data to TOPOSIS, the following were observed:

A1=0.40 building materials/A2=0.80 steel arch/A3=0.55 membrane/A4=0.55 arch of reinforced concrete/A5=0.41 wooden arch/A6=0.68 3-D truss

A2>A6>A4>A3>A5>A1

Therefore, it can be deduced that steel arch is the best work material followed by space structures and concrete reinforced structures.

	Standard Weight	Building Arch	Steel Arch	Membrane	Reinforced Concrete Arch	Wooden Arch	3-D Truss
Tolerance to Flexural and Tensile Load	**7**	Negligible	High	Very High	Very High	Low	Very High
Tolerance to Compressive Force	**7**	Very High	High	High	High	Low in the Direction of Grain	Very High
Execution Time, Investment Turn Over Time	**8**	Low	Very High	Low	Low	High	Very High
Life Span of Structure, possibility of Development and Repairs	**9**	Very High	High	Moderate	Moderate	Moderate	High
Resistance to Wind,	**7**	Moderate	Moderate	Low	Low	Very Low	Low

Humidity, Fire and Earthquake							
Availability of Technology and Construction Materials in Iran	**6**	Very High	High	High	High	Moderate	Moderate
Covering for the Large Opening (meter)	**9**	Low 96	Very High Approx. 1km	Very High 40	Very High 1430	Low 50	Very High 400
Possibility of Pre-fabrication (Material Wastage during Construction)	**7**	Very Low	Very High	High	High	Very High	High
Beauty and Elegance	**6**	High	Moderate	High	High	High	High
Necessity of Precision and Critical Attention to Structure Details	**-8**	Very High	Low	High	High	Moderate	High

CONCLUSION

Efforts were made in this research tostudy and review some innovative aspects of arch shaped structures in the world and to put forth and to express relevant features, advantages and disadvantages. Next, opportunities and challenges of this particular type of structure throughout the country were examined and the priority of selecting these innovative structures based on such conditions was conducted by utilizing the multi-criteria decision-making methods.

Today, the availability of high quality and novel building materials such as concrete and space frames have turned the advanced construction of membrane domes and other structures into reality. Although, a small part of construction projects are carried out using these building systems, but majority of constructions which actually utilize such systems are capable of retaining special performances and in conjunction to rectifying problems normally associated to the state of performance, such systems play a crucial role in the formation of specific symbols and assist in promoting the visual effects and style of architecture of societies.

Considering the events taking place in the modern architecture of Iran today, the application of arch shaped forms is in fact a continuum of what our ancestors started centuries ago. Their work was mostly done without a proper scientific knowledge and merely based on experience and art and dexterity of the craftsmen and their relevant information on existing construction materials. But, anyway they still managed to create masterpieces and feats of architectures which are still talked about today. What we do nowadays is the continuation of their efforts; even though, there are plenty of challenges. But, despite the prevailing obstacles we can reach a certain style of architecture by staying on the same path our ancestors set out on so long ago and by remaining faithful to our past while we have used far better quality materials in construction of our buildings.

The results of this research can be used as a background for architects and engineers in becoming familiar to the specifications and features of innovative arch shaped forms and a reference in selecting these types of structures.

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