Transformable structures

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Abstract. This research explores different types and forms transformable structures as an integral part of any building or construction. The structures, which are capable of changing its spatial position or geometric shape, become an individual branch of architecture and design. However, with all diversity of known structural shape-shifts, there is no comparison of its types with existing buildings. Thus a purpose of this research is studying about worldwide experience in development of transformable structures. Another goal is comparison of known classifications with examples of shape – shifts in built projects based on following study. The internet search along with the review of related literature references was done. By the completion of survey the authors matched given examples with the classification of transformable structures by methods of realization and approaches to motion arrangement. The scissor – structures category is derived into separated stratification as well. The study showed that the structures that can rearrange its shape have a great potential as kinematic objects of architecture and engineering.

1. Introduction

Mankind is interested in mobile architectural elements starting with an ancient time (drawbridges of medieval fortresses surrounding with a moat). The cinema “Udarnik” designed by architect Boris Iofan in 1931 (Moscow, Russia) is one of the first transformable system in architecture of public facilities [1]. Its roof is a stepped dome which can mechanically slide apart. The main function of this roof is protection from outside atmosphere together with energy – efficient conditioning of auditoriums. The key feature of that dome is open – air movie performance, which attracted an audience. Thanks to outstanding architecture and state-of-the-art engineering ideas that cinema became a Moscow’s landmark (figure 1).

Structures capable of changing its geometry was extremely rare recently and considered as a true invention. But in rapidly developing technologies era constructions as «The Rolling Bridge» (London, United Kingdom) with its rolling deck (figure 2) or «Gazprom Arena» (Saint – Petersburg, Russia) with retractable roof became one of the branches of modern architecture and civil engineering.

However, researchers faced a lack of comparison of existing projects and transformable structures classification during looking for its types. That problem turned into the object of research in projects of transformable structures worldwide with pursuit for making a consistent match between classifications and finished projects.
"Transformation" (Latin: transformatio - a transformation) is a shift in shape, appearance, reformation [2]. Transformation is essential for simple movable constructions as cabins, motorhomes, exhibition marquees and complicated public facilities either (transformer – scene of Bolshoi Theatre in Moscow, Russia).

Main reason of transformation is improvement in functional capabilities of buildings and enhance of its convenience. Transfiguration in civil engineering decides long list of problems: to procure a multifunctional architectural spaces, regulation in climate characteristics of rooms, transmission of construction particles to its project position, capability of transition if needed or in case of seasonal changes, minimization of time needed to install or dismantle a structure on construction sight.

2. Methods and approaches
In order to learn about experience in development of transformable structures internet search, review of related literature references along with survey of existing buildings was done [1-12].

3. Research results
Variety of transformation classifications depends on chosen criterion to distinguish them from each other. As a result of the study two criteria were derived: by methods of realization, by approaches to motion arrangement. Transformations of sport venues and scissor – structures were considered in separate criterion.

3.1. Classification by realization method
Spatial, structural, translucent, interactive categories of transformable structures could be identified by method of its realization [3]. Architects and engineers can choose most suitable method among these depending on problem they faced with. When it comes to adjust air characteristics inside of the building, provide cost – efficient air conditioning system or cast a protection from overheating in continuously changing environmental conditions, system, which makes construction facades able to convert itself, should be applied. Intellectual solar shading system of "Al – Bahar Towers" (Abu – Dhabi, UAE) (figure 3); Keifer Technic building with its dynamic aluminum louvers (Styria, Austria) (figure 4 - (a),(b); "One Ocean" thematic pavilion of EXPO 2012 with its moveable lamellas of the kinetic media facade, (Yeosu, South Korea) (figure 5 - (a),(b)).

Spatial methods include approaches to complicate or simplify space boundaries and integrate or disintegrate a room without amendment in building’s dimensions. For single buildings realization of these approaches appears in elements which separate or incorporate a room. For example, transformation happens with sliding walls and panels, movable bulkheads, curtain – dividers. Alteration in volume and shape of pneumatic structures and telescopic expansion of motorhomes are also notable methods. For building complexes realization comes in elements, which combine different
functional areas. All these elements allow to unify several functional procedures together in building by moving in different dimensions.

Figure 3. Intellectual solar shading system of "Al – Bahar Towers" (Abu – Dhabi, United Arab Emirates).

Figure 4. Keifer Technic building (Styria, Austria). (a) - front panel transformation; (b) - front panels after transformation.

Figure 5. "One Ocean" thematic pavilion of EXPO 2012 (Yeosu, South Korea). (a) - front panel transformation; (b) - front panels after transformation.

Transformable space was necessary due to various occupancy for Dee and Charles Wyly Theatre (Dallas, USA). By virtue of spatial methods of transformation architects created an adaptable system of inner space reconfiguration. Theatre was even named after its features as a «mechanical theatre». Delicate solution of absence of adequate area for creativity was proposed by architect Norman Foster. In order to increase exposition area of Sperone Westwater Gallery (New – York, USA) a 3,6 x 6-meter moving room that connects the five floors where works of art are displayed. This lift transports visitors and in the same time serves as supplemental exhibition room if required. Prada – Transformer (Seoul, South Korea) is another sample of museum space transformation. Bearing construction is a steel frame of irregular outer shape. Each face of that shape is unique and corresponds to its own usage scenario when it serves as a foundation. So building can shift its function from exhibition place to a podium.

Structural method of transformation: transfiguration of outer structures (transformation along the wall’s plain, roof transformation), transfiguration of enclosing architectural elements (louvers, screens, panels), rotation.

As an example, parking’s facade of Brisbane International Airport (Brisbane, Australia) consists of thousands punctured small aluminium pieces. These panels appear alike a water surface swaying under gusts of wind and turn a wall into a work of architectural art. London’s architects brought in life "Sliding House" (Suffolk, UK) in which position of movable module around walls and roof causes an alteration of living spaces of this house. Dwellers needs and weather condition governs a stance of this structure which gives a protection for an open air swimming – pool or stained – glass windows of the living room and covers parking and entrance. Rotation of entire building applied in design of "Villa Girasole" (Verona, Italy) driven by a diesel engine, which makes entire construction go around and
follow the sun. Also levels of "Suite Vollard" residential (Italy) are able to rotate independently from each other (figure 6).

Translucent and interactive transformation methods come with light emission and broadcasting on building’s facades. Facade of shopping mall «The Galleria» (Cneonan, South Korea) made of LED – diods serves as a paragon of translucent and interactive methods application. Screen combines two functions: heating protection at daytime and media – board at night time. Media – roofs of «Kazan Arena» (Kazan, Russia) and «Luzhniki» stadium (Moscow, Russia) are perfect specimens of that method.

3.2. Classification by motion arrangement method

Transformable structures might be divided by approaches to motion arrangement criterion into following groups: those which motion is translational and happens along straight or curved way; those which motion is rotational and happens around horizontal, vertical or inclined axis; those which motion is based on folding and unfolding movements.

Translational category appears in multi-purpose stadium "Rogers Centre" (Toronto, Canada). A dome which covers a playing field is divided into four parts. The first one is static, two another are able to move back and forth. The last one, supported by the rollers, can spin around stadium’s axis (figure 7). Olympic stadium "Caja Magica" (Madrid, Spain) is also prominent for its retractable roofs. Each of them relocates itself by tilt or raise. Hereby 27 scenarios of transfiguration may occur. With metamorphoses applicable inside this solution provides a high functional flexibility and abundant diversity of events possible: tennis, gigs, cycle track races, basketball, hockey, box, forums, conference etc.

Roof system of "Mercedes-Benz Stadium" (Atlanta, USA) (figure 8 - (a),(b) and "Qizhong stadium" (Shanghai, China) are considered by the authors as a rotational in its motion arrangement category. Their mechanism based on rotation around different axes and resembles a way how camera’s aperture works [1].

Girders of Kuwait’s pavilion during EXPO – 92 (Barcelona, Spain) are hinged flanks of arches, which look alike fish bones. Transformation goes on rotation of these "bones" around horizontal axis which goes through pinned connection of each beam. This spectacular performance casts a futuristic atmosphere and captivates spectator’s attention. English company Happold Engineering applied the same approach to design a transformation for Venezuela’s pavilion of EXPO – 2000 (Hanover, Germany). Petals attached to its steel frame made its figure verges on palm – tree. Structures of both this EXPO’s was driven by piston system.

Structures driven by expanding and folding mechanism are very rare for bearing construction of buildings and usually remains in a concept only. Chuck Hoberman’s "Iris Dome" proves complexity of such structures to put it under construction (figure 9 - (a),(b)).
3.3. Transformations of sport venues
Transformations primarily present in the bearing systems of sport facilities, so as a result of the study individual classification for transformations in sport venues can be emerged. The following types of architectural and structural adaptation are essential: transformation of the core, tribunes, roof system and entire building [2].

The following methods to change a core might occur: displacement of the pitch in and out of its plain, expansion or reduction of the pitch, rotation of the pitch or its separated areas – by the conversion of the main building’s parts in one word. Transfiguration of the building core allows to host not only athletic but also entertainment events providing a truly multi-functional space. Architects of the "Sapporo Dome" stadium (Sapporo, Japan) followed this approach to create a multi-purpose arena. Realization came in rotation and sliding of the pitch laid on pneumatic cushion. Thus easy shift between baseball and football field is provided.

Addition of tribunes creates an opportunity to adapt a stadium for various events with different capacity. It is important to make a provision for storage of supplemental elements to be casted in place as needed. Building occupancy determines a tribune’s plan: horseshoe, oval, ellipse. This adaptation method takes place in «London Aquatics Centre» (London, UK). If competition with more than regular capacity is needed to be held two temporary wings of tribunes can be added. Once finished and wings are removed Centre occupies much lesser area.

Most common way of transfiguration in sport venues is transformation of the roof system. Its purpose is an adaptation to changes of environmental and weather conditions which is an essential requirement sport venue must meet with. Roof transformation is the most difficult to implement and expensive to design and maintain method, but very efficient at the same time. Such system is necessary for multi-purpose sport facility which serves as venue with different microclimate indicators such as insolation and aeration etc. Every project with retractable roof featured includes innovative architectural and structural solutions, therefore each one is unique. Principal types of roofs in long span structures specified in study [4]. In design of retractable roofs architects usually use domes, hemispheres, thin shells, folded plate structures and cable – stayed roofs.

3.4. Classification of deployable structures
Deployable structures grow from small stacked structure in large expanded configuration. Therefore, they are quite popular when it comes to design of foldable covers for stadiums or movable structures such as temporary bridges, exhibition marqueses, emergency shelters, self-service storages, shading facade systems, construction lifts, solar panels. Deployable structures are widely used in space industry [5]. 4 categories might be extracted according with differences in their structural system: spatial articulated constructions (pinned bars), buckling – wall constructions (pinned plates), cable – pulled and membrane constructions [6]. A lot of deployable systems are scissor – like constructions.
The first proposal to use spatial articulated constructions was made by Spanish engineer Emilio Pérez Piñero in project of a dome for theatre (Spain) [7]. Foldable roof for swimming pool (Seville, Spain) is another example of spatial articulation for structure transformation. Elastic membranes or rigid plates which overlaps once folded serves as a cover for these roof system making theirs functioning efficient and quite durable.

Facade systems which procure a solar protection for building situated in hot climate regions are great example of buckling – wall constructions.

Cable Scissors Arch is an example of cable – pulled structure where hinges of pinned bars connected with cable driven by a pulley. Arch rise changes respectively to tension force developed in the cable by a pulley. Entire construction resembles an array of scissors (figure 10 - (a),(b)).

Foldable membrane constructions are usually driven by pneumatic mechanisms. Air injection in between membranes runs entire transformation of such structures. Scope of inflatable structures is temporary housing, command centers, shelter for equipment and machinery etc [8]. Air gap between membranes creates a good heat insulation and perfectly feet for regions very cold or hot climate.

4. Conclusion
This survey on transformable structures postulates following conclusions:

- use of transformable structures allows to adapt buildings to different functions, expand its possible scope and create multi – purpose spaces;
- architectural transformation is an advanced approach in design of unique buildings;
- adaptability to changing occupancy demand allows to cure building’s functional exhaust.

Research on worldwide experience in design of transformable structures shows that they have a great potential in field of kinetic architecture and engineering. Computer aided design drastically relieves development and design of transformable constrictions and opens new horizons for improvement of architectural, functional and aesthetic aspect of the world around us.
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