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THE ARCHITECTURE OF SOLID AND RETRACTABLE ROOFS

ARCHITEKTURA DACHÓW STAŁYCH I RUCHOMYCH

Abstract

One element that impacts the visual perception of retractable roofs is their geometrical construction. A quest to find new and attractive forms for buildings' roofs presents a challenge for architects and designers. In this study, an attempt has been made to classify the roofs in terms of their architectural form. The roofs covered in the research are solid as well as moveable. Solid roofs are divided into three categories i.e. plane, curvilinear and freeform. Two criteria apply when classifying retractable roofs. One is the type of motion that the roof is performing (rotational and sliding) and the other is the type of material that roof panels are made from (roofs with rigid and variable panels).

Keywords: membrane, plane, curvilinear, freeform, with rigid and variable panels roofs

Streszczenie

Jednym z elementów wpływającym na odbiór przekryć ruchomych jest ich budowa geometryczna. Poszukiwanie nowych form zadaszeń obiektów architektonicznych to jedno z ważniejszych zadań stawianych projektantom i architektom. W niniejszej pracy podjęto próbę uporządkowania i sklasyfikowania przekryć dachowych pod kątem ich formy geometrycznej. W obszarze badań znalazły się zarówno zadaszenia stałe, jak i te, które wykonują ruch. Dachy stałe podzielono na przekrycia o połaciach: płaskich, krzywoliniowych i złożonych. W zakresie ruchomych zadaszeń przyjęto dwa kryteria ich podziału: rodzaj ruchu wykonywanego przez dach (obrotowy i przesuwny) oraz rodzaj materiału tworzącego panele dachowe (wyodrębniono dachy z panelami sztywnymi i zmiennymi).

Słowa kluczowe: przekrycia membranowe, dachy z połaciami płaskimi, krzywoliniowymi i złożonymi, zadaszenia z panelami sztywnymi i zmiennymi

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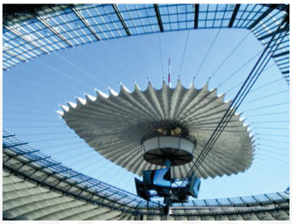
1. Introduction

A rapid progress in new technologies brings about new challenges for designers and architects and, at the same time provides them with virtually unlimited possibilities in terms of shaping architectural buildings. Computer-aided design software allows for creating and modelling of solids and surfaces of any shape. It leads to new, original and spectacular solutions. According to the trio: Firmitas (Firmity), Utilitas (Utility), Venustas (Beauty), the three principles that define architectural features, coined by Vitruvius and still very much in use [1], it is the shape of an architectural building that determines its beauty. The form is the element that attracts attention, has emotional impact, and as a result, conveys the sense of beauty.

a)

b)



c)

Ill. 1. PGE Narodowy in Warsaw – roof as seen:
a) from outside (source: https://ro.wikipedia.org/wiki/Stadionul_Na%C8%9Bional_din_Var%C8%99ovia#/media/File:Warszawa,_Stadion_Narodowy_-_fotopolska.eu_%28331614%29.jpg, online: 06.12.2015),
b) from inside (source: https://pl.wikipedia.org/wiki/Stadion_Narodowy_w_Warszawie#/media/File: POL_Stadion_Narodowy_Warszawa_09.jpg, online: 06.12.2015),
c) from inside with a variety of illumination (source: https://pl.wikipedia.org/wiki/Stadion_Narodowy_w_Warszawie#/media/File:Narodowy-otwarcie16.JPG, online: 06.12.2015)

The roof is the part of the building that has a considerable impact on its perception. Roof shapes can be flexibly modelled and formed. In this study, an attempt has been made to classify the roofs of architectural buildings in terms of their architectural form. Roofs that are solid and those that can move were covered in the research. A movable roof can significantly change the shape of a building, and there is a different perception of the roof in its open or shut form. What distinguishes solid and retractable roofs is their construction which for the latter, is visible not only from the outside, but also from the inside of the building. The changing shape of the roof attracts the attention of the viewers, hence particular care is taken by architects and designers of its aesthetics and form. The PGE Narodowy in Warsaw is a typical example of that. It is one of the biggest textile rooftops in the world, covering in the area of eleven thousand square metres. Pictures in Ill. 1a and 1b show the Stadium viewed with its roof open and shut; from the outside and inside respectively. If not covered or obstructed by any object, the roof part of the building constitutes an integrated element of the interior, and during cultural or sports events, plays a decorative role (Ill. 1c). Being flexible and adaptable [2], retractable roofs enhance buildings with a variety of possible uses for outdoor or indoor activities, due to their ability to react swiftly to changing weather conditions. The multi-functionality of retractable roofs is undeniably their greatest asset [5].

The main purpose of the study is to determine the retractable roofs whose shape changes several times during the movement. The researches begun with the classification of the retractable roofs based on their geometry. Because their shape is often determined by the solid roof (it is often a part of the solid roof), a review of the solid roofs shapes was done.

2. Solid roofs

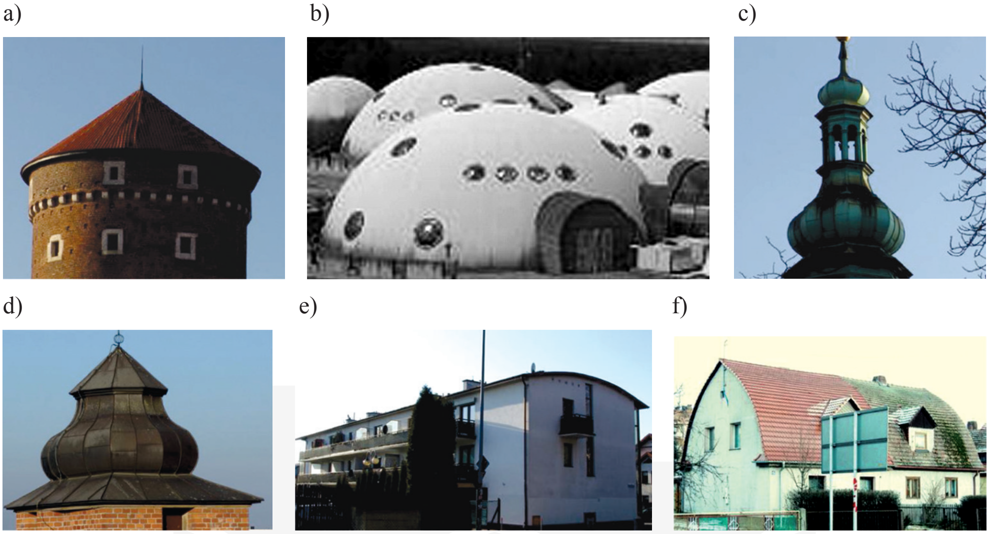
Basic classification divides solid roofs into two categories i.e. plane or curvilinear [8]. The plane category includes: flat, shed, gable, hip, half-hip, gablet, mansard, monitor (Polish), pavilion, helm, butterfly and saw-tooth roofs. Ill. 2 presents selected examples of this type of roofs.

The curvilinear category takes the following: conical, dome, onion-shaped, bell, barrel, saddle, barrel, rainbow, vaulted, corrugated and parabolic roofs (Ill. 3).

Ill. 2. Plane roofs:

a) flat (source: https://pl.wikipedia.org/wiki/Zielony_dach#/media/File:20080708_Chicago_City_Hall_Green_Roof.JPG, online: 06.12.2015),

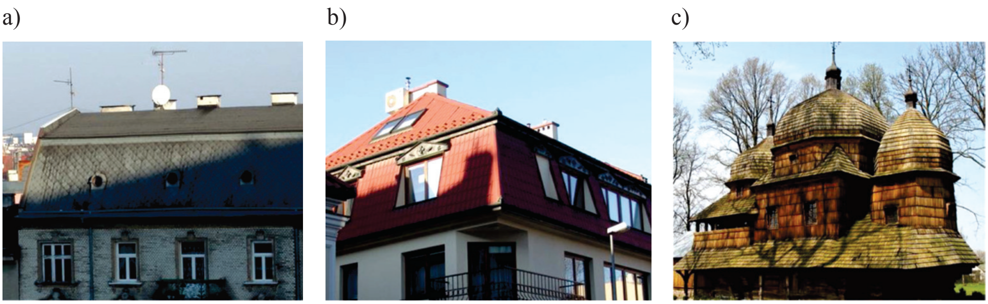
b) gable, c) half-hip (photos by K. Romaniak), d) gablet (source: https://pl.wikipedia.org/wiki/Dach_p%C3%B3%C5%82szczytowy#/media/File:Zakopane_Droga-do_Rojow_2_dom_drewniany_02_A-1100_M.JPG, online: 06.12.2015), e) mansard, f) monitor, g) pavilion, h) butterfly, i) saw-tooth (photos by K. Romaniak)



Ill. 3. Roofs of curvilinear planes: a) conical (photo by K. Romaniak), b) dome (photo by A. Pawlak--Jakubowska), c) onion-shaped, d) bell, e) barrel (photos by K. Romaniak), f) rainbow (source: https://pl.wikipedia.org/wiki/Dach_kr%C4%85%C5%BCynowy#/media/File:Kluczbork,_zabudowa_ul._Byczy%C5%84skiej.JPG, online: 06.12.2015)

This classification, in which the dividing criterion is the shape of the rooftop area, does not exhaust all possible solutions. Roofs within each group are subject to further divisions. Mansard roofs, for example, may appear in an apex/ pitched (gambler) (Ill. 4a) or a hip form (Ill. 4b). Neither does the classification cover elements that can change the form of the roof such as dormers (Ill. 4c).

The development of computer technologies and progress in the building material industry provides a vast number of opportunities for designing roofs that escape any classification. The form of such roofs is, more frequently than not, very complicated and difficult to classify under any category. Hence a new group of solid roofs has been determined and referred to as roofs of complex areas [7]. These mainly appear in a form of membrane rooftops with panels made from fabric (Ill. 5 a–c).



Ill. 4. Examples of roofs: a) gambler roof, b) mansard hip roof with dormers (photos by K. Romaniak), c) roof with plane and curvilinear areas (source: https://pl.wikipedia.org/wiki/Cerkiew_Narodzenia_Przenaj%C5%9Bwi%C4%99tszej_Bogurodzicy_w_Choty%C5%84cu#/media/File:Chotyniec_cerkiew2.JPG, online: 06.12.2015)

a)

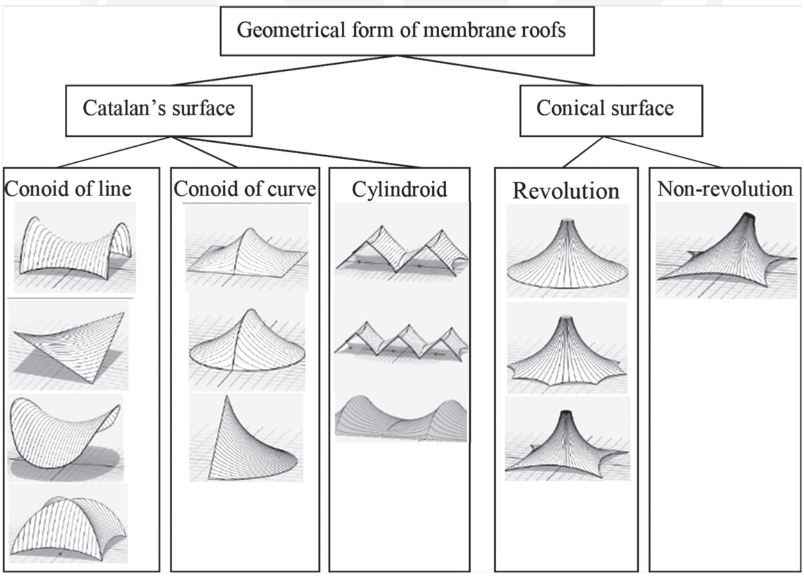
b)

a)

b)

Ill. 5. Examples of roofs of the following shapes: a) hyperbolic paraboloid [10] (photo by K. Romaniak), b) parabolic conoid (photo by A. Pawlak-Jakubowska), c) dome (source: https://en.wikipedia.org/wiki/Millennium_Dome#/media/File:Millennium_Dome_1.jpg, online: 06.12.2015), d) cone (photo by A. Pawlak-Jakubowska)

In terms of geometrical form, membrane rooftops often take spectacular and unique shapes featuring softness and plasticity. They fall into two fundamental groups i.e. Catalan's surface and conical planes (Ill. 6) [3, 4].



Ill. 6. Most common geometrical forms of membrane construction (by A. Pawlak-Jakubowska)

Shaping a rooftop with the use of digital technology results in obtaining freeforms of the B-Spline type and NURBS (Ill. 7).

a)

b)

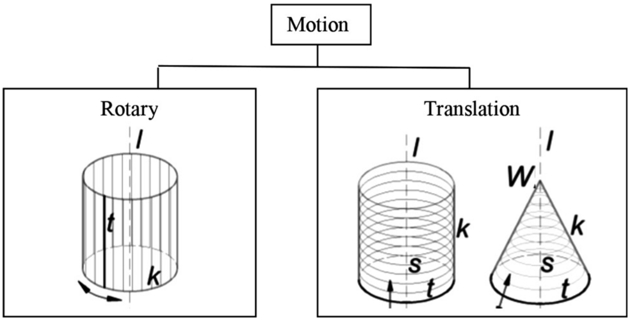
c)

Ill. 7. Free forms of NURBS type: a) Salvador Dali Museum in St. Petersburg in Florida (source: https://commons.wikimedia.org/wiki/File:St._Pete_Dali_Museum03.jpg, online: 06.12.2015), b) Centre Pompidou-Metz in Metz (source: https://de.wikipedia.org/wiki/Centre_Pompidou-Metz#/media/File:Metz_Centre-Pompidou_2011-3_2.JPG, online: 06.12.2015), c) Złote Tarasy in Warsaw (source: https://en.wikipedia.org/wiki/Z%C5%82ote_Tarasy#/media/File:Zlote_tarasy_zima2011.JPG, online: 06.12.2015)

Roof architecture includes not only his shape, but also building technology and the function of the roof and object. Among the solid roofs, the flat roof creates special opportunities in terms of changing its function. It can be used as additional living space, in the form of a terrace or garden. This space is especially valuable in the cities, creating the opportunity to be among the greenery and outdoors. The roof then has leisure and recreational functions.

3. Retractable roofs

Two criteria apply when classifying retractable roofs. One is the type of motion that the roof is performing [6] and the other is the type of material that roof panels are made from. Within the first criterion, there are roofs that perform the following:
– rotary motion – rotation of the generatrix around the axis of the plane,
– advance motion – translation 'extension' of the generatrix along the straight line plane directrix (Ill. 8).

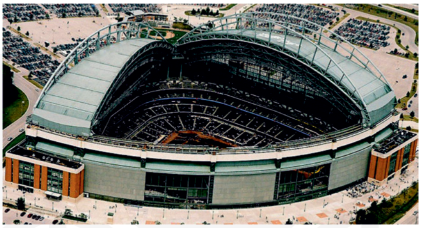


Ill. 8. Retractable roofs divided by the type of motion (by A. Pawlak-Jakubowska)

Illustration 8 presents rotary and translation motions performed on cylinder and cone planes. Similar translation takes place on other planes, such as sphere or torus. In Table 1, there are examples of selected buildings in which the above-mentioned types of motions are performed. Each rooftop is shown in its open and shut form.

Table 1

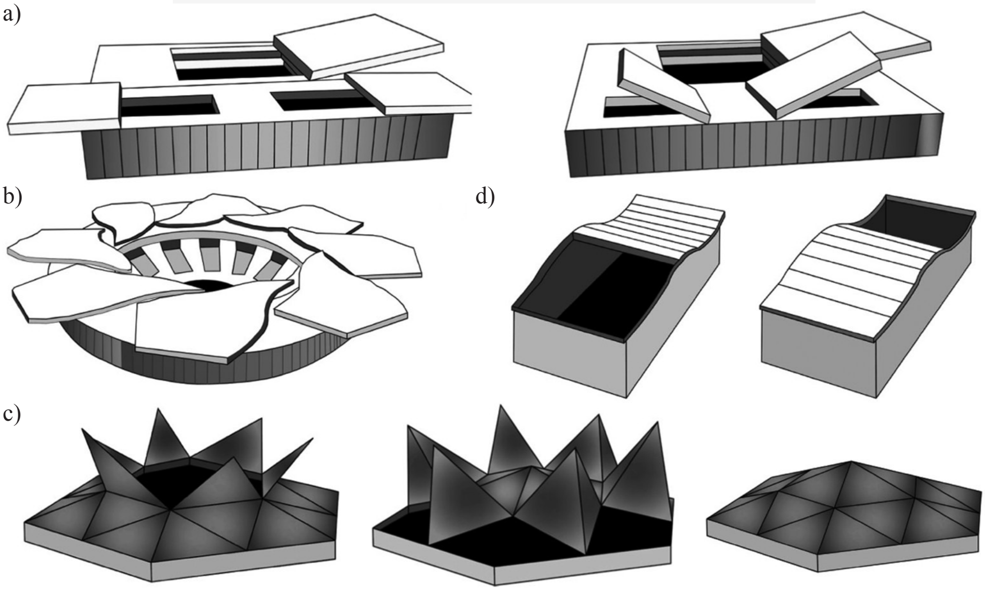
Retractable roofs performing rotary and translation motions

No.	Plane	Motion	Roof
1	Torus	rotation	
			Miller Park, Milwaukee, USA (2001), capacity – 41,900 people (source: https://fr.wikipedia.org/wiki/Miller_Park_%28Milwaukee%29#/media/File:Miller_Prk.jpg, online: 06.12.2015)
2	Cylinder	rotation	
			Millennium Stadium, Cardiff, England (1999), capacity – 74,500 people (source: https://en.wikipedia.org/wiki/Millennium_Stadium#/media/File:Millennium_Stadium_%28aerial_view%29.jpg, online: 06.12.2015)
3	Cylinder	translation	
			Seagaia Ocean Dome in Miyazaki, Japan (1993) (source: https://en.wikipedia.org/wiki/Seagaia_Ocean_Dome#/media/File:SeaGaia_-_Miyazaki_Ocean_Dome_-_outside.jpg, online: 06.12.2015)

Similarly to the one for solid roofs, this classification of retractable roofs does not cover all possible solutions. Examples of rooftops that escape the classification are presented in Ill. 9 as follow:

– rooftop Caja Magica in Madrid performs a rotary as well as a translation motion (Ill. 9a),
– individual elements of the rooftop of Qi Zhong Stadium in Shanghai move along a circular runner, hence the motion performed is called rotary (Ill. 9b),
– panels of the Duisburg Theatre rooftop advance along a smooth curve (Ill. 9c),
– triangular panels of the Media Park roof in Sapporo rotate around straightforward axes (Ill. 9d).

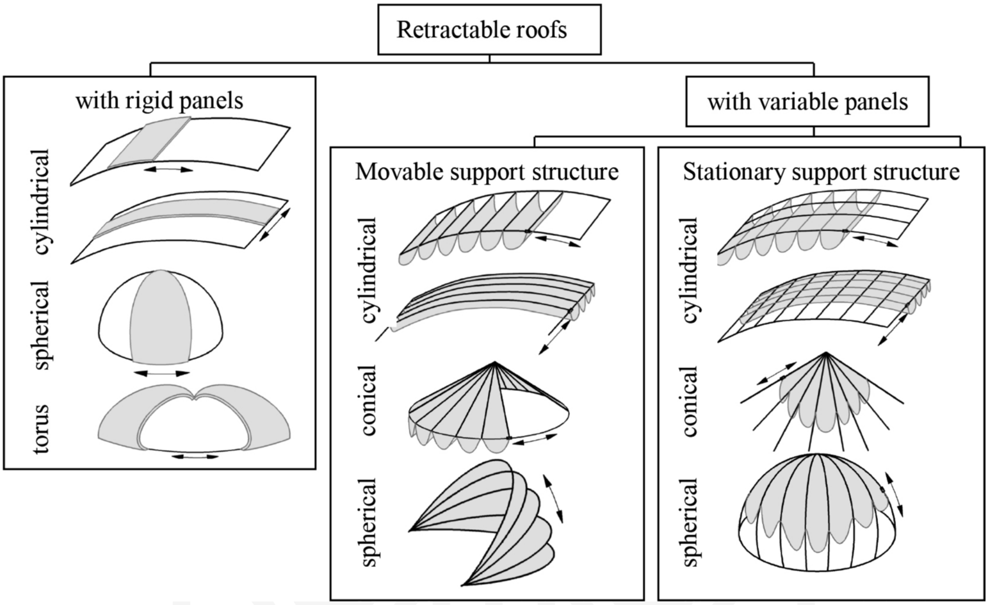
In the next classification, the retractable roofs are divided into roofs with rigid or variable panels. The classifying criterion is the material that the panels are made from. Rooftops with rigid panels are invariable in shape during translation, whereas roofs with other panels, made of textile material, vary in shape while moving.



Ill. 9. Various shapes of retractable roofs (diagrams): a) Caja Magica, Madrid, Spain, b) Qi Zhong, Shanghai Stadium, China, c) Duisburg-Nord Theatre, Germany, d) Media Park, Sapporo, Japan [9] (by K. Romaniak)

Two more groups of roofs with variable panels were determined, which differ in the manner of construction. First, with a stationary support structure along which the traction moves (Kadzielnia, Kielce, Poland), and the other with a movable support structure which itself performs the movement itself (Toyota Stadium, Japan).

This work presents the examples of rigid and movable roofs which represent only a fraction of actual real-life solutions. Nonetheless even those examples point out to an extraordinary diversity in terms of geometrical forms, which can be obtained. Membrane roofs and those modelled with computer software (NURBS surfaces) take a very important place amongst the roofs discussed.



Ill. 10. Geometrical classification of retractable roofs with rigid and variable panels (by A. Pawlak--Jakubowska)

4. Conclusions

One element that impacts the visual perception of retractable roofs is their geometrical construction. A quest to find new and attractive forms for architectural buildings presents a challenge for architects and designers. Classifications of roofs, both rigid and retractable, show their unlimited diversity and richness in terms of shapes and solutions regarding construction and materials they can be made from. The process of making retractable rooftops requires not only the creativity of the designer, but also the technical innovativeness of engineers and constructors. Each one of such undertakings is a synergy of tasks performed by specialists of architectural design, construction and the structure of mechanisms. The next stage of research will be the analysis of roof building technology and functionality associated with the type of roof. The classification of roofs, both solid and retractable, organizes information with respect to their geometry. Classification criteria of retractable roofs adopted in this paper are related to the movement, because the main purpose of the research is to find the roofs with different geometries, which change during the movement.

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