The Distinction between Mushroom and Umbrella Structures in Slovene Architecture

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Abstract. A brief historical overview of the development of tree-inspired structures is given first. It starts with the world's first three mushroom slab constructions built from 1906 to 1908 and continues with several tree-inspired roof structures of the first half of the twentieth century. The main part of the paper describes eight selected buildings in Ljubljana, Slovenia, all of them examples of mushroom or umbrella structures made of reinforced concrete. The oldest described building is an experimental structure from 1933, then come two pavilions built at Ljubljana's Exhibition Centre, three different examples of gas stations, canopies for cars, and canopies at the Ljubljana's main railway station. Except the oldest one, all were built in the 1960's and early 1970's. The buildings are compared quantitatively regarding their overall size, shape of the roof, and the number of the repetitive structures these buildings are made of. The type of each described structure is examined and compared to others. Laymen and even some experts often use the terms mushroom and umbrella structure imprecisely, the indifference and the lack of knowledge being the most probable reasons. Based on the presented analysis it is asserted that the distinction between mushroom and umbrella structures must be made regarding how the load force is transferred from the roof to the pillar. This distinction should also be made first when classifying recently built tree-inspired structures.

1. Introduction

The essential feature of a tree-inspired structure is a roof supported by a single central pillar and its foundation. Often called dendriforms, calices, or lily-pads in the past, different tree-inspired structures are nowadays described mostly as mushroom or umbrella structures. Even though there are certain differences between these kinds of structures, most authors, predominantly art historians, do not define the terms mushroom and umbrella structure precisely and often do not bother to make the distinction clear. This paper aims at clarifying this distinction using the existing tree-inspired structures in Ljubljana, the capital of Slovenia, as case studies.

From the structural point of view, the tree-inspired roof structures are cantilever structures. Each such tree-inspired roof structure consists of a roof that is supported by one pillar (column or vertical beam) only and a foundation underneath. The load is transferred from the top of the roof through the pillar, where it is subjected to compressive stress and maybe buckling, further to the foundations, where it is resisted by the moment of force and shear stress. The tree-inspired roof structures are also inverted pendulum type structures, because more than 50% of the mass of the entire structure belongs to the upper part of the structure, i.e., above the pillar.

The idea of the tree-inspired roof structure was especially popular in world architecture during the third quarter of the twentieth century. A brief historical overview of these structures has been described

by Rian and Sassone [1]. Mushroom and umbrella structures were also quite popular in Slovene architecture during the 1960's and early 1970's. Some case studies have already been included in the historical analysis in the context of Slovene structuralism [2]. This paper contains a comprehensive study of tree-inspired structures in Ljubljana, Slovenia. Based on the included case studies, the paper focuses on making a clear distinction between mushroom and umbrella structures in general and thus on clarifying the existing terminology.

2. The history of the tree-inspired structures

The tree-inspired roof structures can be found in literature under many different names. Many of them are named after their shapes: dendriforms, lily-pads, mushrooms, or umbrellas. These terms are not defined precisely although there are certain differences between these structures. The historical overview of the development of these structures seems to be appropriate.

2.1. The origins of the tree-inspired structures

The origin of the tree-inspired roof structure is a mushroom slab construction, an early twentieth century type of reinforced concrete structure. The mushroom slab construction consists of a beamless reinforced concrete floor construction and roof supported by columns with widely flaring heads having horizontal rings of reinforcement to support the floor slab and roof. The tops of the columns are shaped to form a circular disc much bigger than the diameter of the column. As the shape of the top of the column is reminiscent of a mushroom-like form, the structure is named upon it. The type of the columns in a mushroom slab construction later became to be known as mushroom columns.

The development of the mushroom slab construction started at the beginning of the twentieth century. Almost at the same time three innovators, Turner in Minneapolis, Loleit in Moscow, and Maillart in Zürich, designed and realized their own mushroom ceiling constructions in steel-reinforced concrete [3]. The American engineer Claude A. P. Turner patented his "mushroom system construction" in 1905 and built his first mushroom ceiling in 1906. In 1907 the Russian engineer Artur Ferdinandovitch Loleit started to construct an experimental mushroom ceiling with pillars formed like flutes and circular skylights between them. However, he presented his method in a lecture as late as in 1912. The Swiss engineer Robert Maillart built his first experimental system of flat slabs supported on columns with enlarged capitals in 1908, patented this "mushroom" system one year later, and in 1910 built his first beamless slab floors supported on "mushroom" columns in the Giesshübel warehouse in Zürich. In all these early projects, the advantages of a mushroom ceiling as an integral system of columns and slabs without beams were obvious from both structural engineering and architectural point.

2.2. The first tree-inspired structures

In 1936 the Danish architect Arne Jacobsen designed small gas station in Skovshoved, Denmark [1]. It consists of one shed roof that covers both, a gas pump and a cashier's building. The thin roof over the pumps has the oval shape measuring 6.4×9.6 m and is connected to a rectangular canopy of 3.2×4.8 m that leads further to the roof over the 9.6×14.4 m cashier's building. In the center, the oval roof is supported by 4.5 m high mushroom column. This is one of the earliest known examples of a single roof supported by a mushroom column. The gas station building has been constructed in reinforced concrete, at that time relatively new material that allowed architects and engineers to build structural forms in new shapes. Because of the shape of the roof over the gas pump, the building was given a simple name: Paddehatten, a Danish word for a mushroom. Today Jacobsen's gas station is preserved and well restored example of the functionalist style typical for the time.

Frank Lloyd Wright applied tree-inspired structures to great effect in the Johnson Wax Administration Building, Racine, WI, USA (1936–39), where a tree-like shape is incorporated via a tall slender tubular mushroom column upon which a glass ceiling is placed. The diameter of each column is 23 cm at the bottom and 550 cm at the top, where it expands to a "calyx" or a mushroom like form. The

8.5 m high columns are mostly hollow, the walls being only 9 cm thick [4]. Many doubted such a column can bear 12 tons of material and thus the building inspectors required a test column to be built in advance to test the idea. However, when the column was experimentally tested, a load of 60 tons, 5 times of what was required, had to be used to overload the column. Overall, the building contains three different types of skilfully designed columns shaped as lily-pads or mushrooms and called "dendriforms" by Wright [4]. The Johnson Wax Administration Building was included among National Historic Landmarks in 1976.

During the 1930s, the French civil engineer Fernand Aimond designed and constructed several hyperbolic paraboloid (hypar or HP) roofs in France for aircraft hangars and workshops. Many of them were built as a series of roofs, where each roof was supported by one pillar described as an umbrella [5]. For the Cuers-Pierrefeu airship base (1933–36) he used 30 saddle-type HP structures; each was 3 cm thick and measured 12×7 m and was supported by a single pillar. For Workshops for the School of Naval Mechanics at Rochefort (1936) Aimond used 56 HP umbrella shaped structures of 14.6×13.7 m, each being 4 to 5 cm thick and again resting on a single pillar only. For an aircraft hangar at Limoges-Feytait (1935-36) he designed a roof composed of 16 HPs that were supported by only 4 columns; each HP was 5 cm thick and measured 10.25×12. For two aircraft hangars, the first one at Lanvéoc-Poulmic (1934–37) and the second at Châteaudun (1937–39), he used the same design but on an impressive scale: each hangar is made of 8 large umbrellas with dimensions 36×36 m, each formed from many 5 cm thick HP shell segments. The total area covered by one hangar is 171.5 m by 88.5 m. Because of his significant contribution Fernand Aimond could be considered the father of the thin hyperbolic paraboloid concrete shells.

Fernand Aimond's work was continued by the Italian engineer Giorgio Baroni, who experimented with reinforced concrete umbrella structures in 1938 [1]. The Argentine architect Amancio Williams started the project of an umbrella shell roof of minimal thickness just a year later. In 1944 the American architect Louis Kahn made plans for the Parasol House which was meant to promote inexpensive housing. The house with the prefabricated umbrella-like structure was never built, but with a series of square canopies each cantilevered from a single pillar and with a roof as a sort of an egg crate sandwich panel with open webs [6], it was an interesting novelty. However, all these remained projects only and were never realized.

2.3. The expansion of the tree-inspired structures after WWII

The Spanish and Mexican architect Felix Candela improved Aimond's work. From 1952 to 1968, he designed, tested and constructed many HP inverted umbrella structures [7]. His first prototype of a roof was created by joining four straight-edged hyperbolic surfaces: the shell structure was 3.8 cm thick, measured 10×10 m and rose from the capital little more than 90 cm. During the next 10 years, Candela covered - mainly as industrial buildings - more than 280 000 m2 with different umbrella structures. Throughout these years his HP structures become ever more rational. Candela's graceful structures reach perfection not only as engineering but also as art objects.

The Spanish architects José Antonio Corrales and Ramón Vázquez Molezún designed the Spanish Pavilion at EXPO '58 in Brussels as a prefabricated forest of 130 steel umbrella structures [8]. Each umbrella structure consists of a hexagon roof with 5 m long steel ribs supported by a 6 m high steel circular column (with a gutter hidden inside). For the USA Pavilion on the American National Exhibition 1959 in Moscow, the American designer George Nelson used 90 glass fibres umbrellas, each of them 6 m high and with a roof 4.8 m in diameter. Eero Saarinen and the Eameses designed IBM Corporation pavilion for 1964 World's fair in New York as a forest of 54 steel trees with explicit branches and more than 10 m high [8].

At the beginning of the 1960s many architects all over the western world started using mushroom or umbrella structures for public buildings. The Hungarian-born architect and designer Marcel Breuer built Hunter College Library (today Lehman College Art Gallery) in New York (1960). He used 6 hyperbolic paraboloid inverted umbrellas made in reinforced concrete, each being a square measuring 18.3×18.3 m. The Italian engineer and architect Pier Luigi Nervi designed Palazzo del Lavoro, Turin (1961), consisting of 16 units, each made of 20 m high reinforced concrete pillar and 20 steel ribs for 22×22 m square roof umbrella structure. The aforementioned Louis Kahn developed the idea of his Parasol House and built the Olivetti-Underwood Factory in Harrisburg, Pennsylvania (1966-70), consisting of 72 prestressed concrete units in an 8×9 grid. Each roof element is a prismatic concrete shell 15 cm thick and 9 m above the factory floor. Natural light is reaching the factory floor through windows at the corners of each roof unit. Each column is designed also as a gutter.

3. The tree-inspired structures in Ljubljana

The first tree-inspired structure was built in Ljubljana as early as in 1933, but it took some time before more innovative projects became feasible again in 1960s after long years of post-WW2 reconstruction.

3.1. Franjo Dědek: car repair canopy

In 1933, the Slovene structural engineer Franjo Dědek (1866-1939) constructed the first tree-inspired structure in Ljubljana, Slovenia. Although an experimental one, it served as a car repair canopy. As shown in figure 1 (that was used as an advertisement for Dědek's construction company), the structure consists of a single roof that is almost flat, made of reinforced concrete, and is covered by pieces of metal. It is shaped as a 10×10 m square, with 8 ribs that spread from the central octagon pillar to the edges and corners, and 4 ribs that are parallel to the edges of the roof. One of the first of its type in the world, this unique structure had been the only tree-like structure in Ljubljana for more than 30 years. Nowadays, despite its bad condition that desperately calls for restoration, it still serves as a canopy over a small car parking.

Figure 1. Advertisement for Franjo Dědek's construction company [9] and photo [10] of the structure

3.2. Marko Šlajmer: Jurček Pavilion

Marko Šlajmer (1927-69), an architect, and Ivo Vodopivec, a structural engineer, designed the first mushroom structure in Slovenia [11]. The Jurček pavilion, built in 1960 at Ljubljana Exhibition Centre, is named after the boletus mushroom (Jurček in Slovene). The structure is made of just one reinforced concrete 6 m high mushroom pillar and a circular roof of 27 m in diameter as seen in figure 2. Hence, the roof covers a ground floor of 500 m2. The façade of the pavilion is made as a curtain wall and made of a prefabricated fully glazed elements placed in an aluminium profile. The pavilion, built in 5 months only, is situated close to the main street and thus it appears as a large exposition window [12, p. 17]. The transparent façade of Jurček pavilion was an important novelty in the Slovene architecture. Firstly, as a curtain wall façade it introduced a new concept of a completely transparent building to the Slovene architecture. Secondly, it exposed the iridescence between the inner and the outer space not familiar in Slovenia before. Just a few years earlier, Marko Šlajmer designed the first prefabricated steel building in Slovenia (also at Ljubljana Exhibition Centre in 1958). By designing Jurček pavilion he established himself as one of the most innovative architects of his generation.

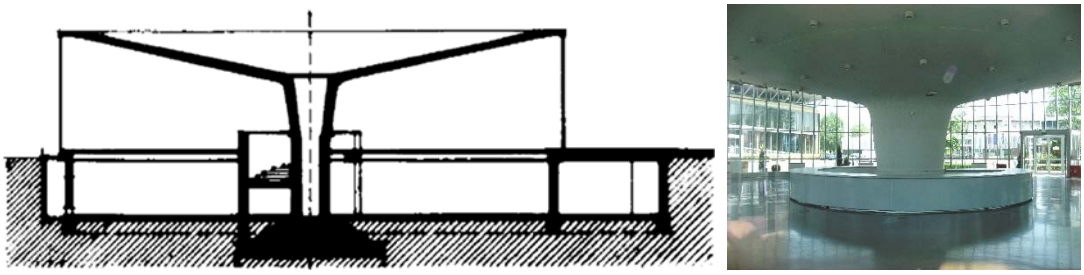

Figure 2. Cross-section [12] and photo [10] of the Jurček pavilion

3.3. Milan Mihelič: Hall C

Another pavilion at Ljubljana Exhibition Centre was designed by a team consisting of Milan Mihelič (1925), the architect, and Jože Jaklič, the structural engineer, in 1965-67. The original design for Hall C was influenced by Japanese Metabolist movement and should have been made of 26 similar elements. This incorporates the idea of an adjustable construction which allow organic expansion in compliance with the program and functional requirements of the Exhibition Centre [13 pp. 35-39]. In 1967 they built smaller pavilion made of only 4 reinforced concrete elements in a single line (figure 3). Each element consists of an octagonal roof with a side of 22 m, supported by 6 m high pillar and a foundation. The reinforced concrete structure has been completely renovated in 2000.

The Slovene art historian Stane Bernik described the Hall C element in his book on Slovene architecture of the 20th century [14] twice, each time differently. The first time he describes it as "Mihelič's Pavilion C (1965-1967), spreading in all directions, with an umbrella construction, glass walls and concrete articulated cover" [14, p. 318). But the second time he describes its basic element as follows "The pavilion element is formed by a reinforced concrete pillar that supports the mushroom octagonal roof, in which shades are hung on the glazed fronts on the eastern and western sides. With the considered design syntax and softened visible elementary expression of the reinforced concrete construction, Hall C ranks among the most eloquent structural solutions here." [14, p. 360]. In the same book, the same author describes the same structural element differently: the first time it is called "an umbrella construction" and the second time "a pillar that supports the mushroom octagonal roof". The art historian does not know the difference or he just does not care?

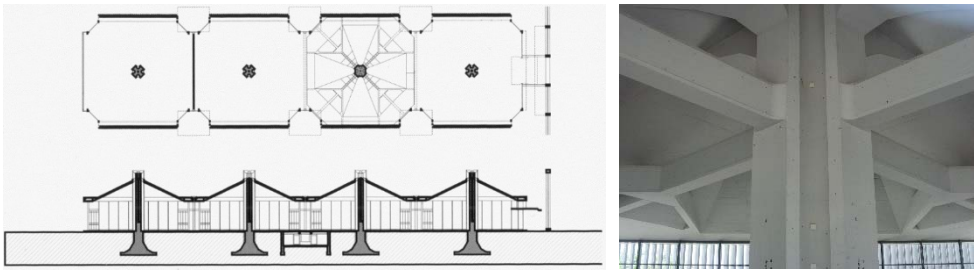

Figure 3. Roof plan [14], cross-section [14], and photo [10] of the Hall C

3.4. ***Milan Mihelič: gas station in Tivolska street***

In 1967-68 the same team, Milan Mihelič and Jože Jaklič, designed "Petrol" gas station at Bavarski dvor. At that time Bavarski dvor, built near Ljubljana main railway and bus station, was planned to become a business center. The structure of the gas station is a 7.1 m high reinforced concrete umbrella structure with a 19.2×19.2 m square roof. More precisely, a single pillar supports the roof via diagonal ribs. At each side of the roof, there is a concrete block bearing the logo of Slovene oil company Petrol. But in the contemporary review published in Sinteza, the Slovene art journal, the roof is described as "a mushroom concrete structure" [15, pp. 36-37]. As shown in figure 4, the umbrella structure shows clear signs of artistic, or almost sculptural, design. Unfortunately, only one gas station of this kind was ever built. Today it is abandoned and overshadowed by numerous new buildings which have been built later.

In 1980 the aforementioned Stane Bernik described this building: “The Petrol station, with its characteristic mushroom-like structure, is intended to form a constituent part of the future business centre Bavarski dvor.” [13, p. 67].

The design of this particular gas station was presented in the German journal Bauwelt [16] and thus represents one of the very few buildings of Slovene postwar architecture made known abroad.

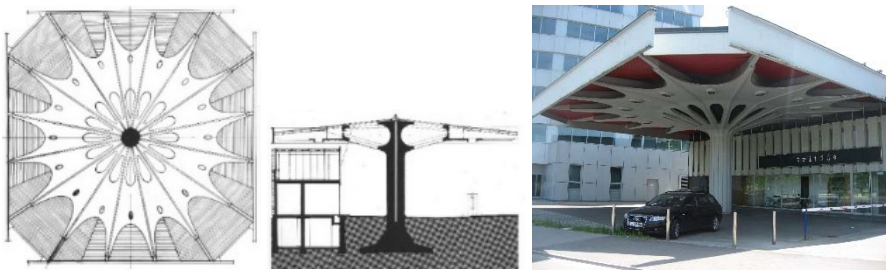

Figure 4. Roof plan [15], cross-section [15] and photo [10] of Mihelič’s gas station

3.5. *Edvard Ravnikar: gas station in Tivolska street*

Edvard Ravnikar (1907-93) one of the most prolific architects of Slovene postwar architecture and by all means the most influential Slovene architect in the second half of the twentieth century. Together with the structural engineer Ervin Prelog he designed and built a gas station, just across the street from the gas station designed by Mihelič and described above. The building, constructed in 1968-69, consists of three separate identical reinforced concrete mushroom structures in a row and a small cashier’s building cubicle nearby (figure 5). Each mushroom structure is made of octagon pillar that supports the mushroom square roof with a side of 19 m [15, pp. 38-39]. The pillar is 3 m high with a 3×3 m square foundation. In the aforementioned journal Sinteza, the roof above the gas pumps is described as “a mushroom reinforced concrete structure” [15, pp. 38-39]. The mushroom structure has been completely renovated during the 1990s and is still in a very good condition today.

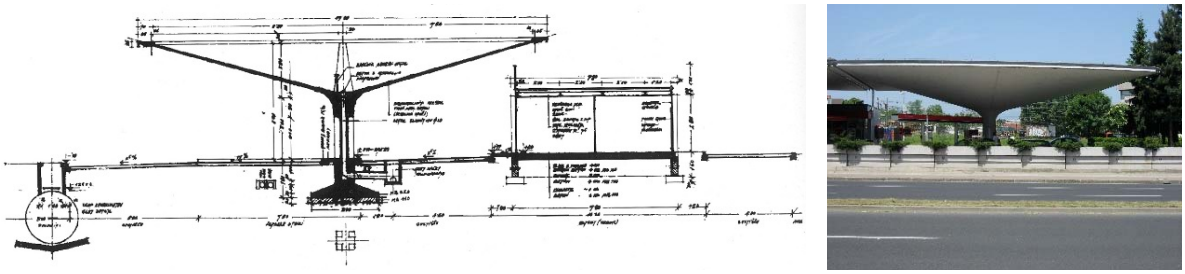

Figure 5. Cross-section [15] and photo [10] of Ravnikar’s gas station

3.6. *Canopies for cars in Celovška street*

Another reinforced concrete roof structure was constructed in Celovška street, just 50 m from Dědek’s car repair canopy, the oldest tree-like structure in Ljubljana. This canopies were built during 1969-70 and consist of six roofs in a single line. Each roof is shaped as a10×10 m square and stands on a 5 m high pillar (figure 6). The ribs go from the centre of each side to the octagonal central pillar. Underneath the canopies there are two separate cubical buildings.

3.7. *Gas station in Dunajska street*

Yet another gas station was built in Dunajska street just across Bežigrad Central Stadium, the oldest stadium in Ljubljana. The reinforced concrete structure consists of six similar roof elements constructed in two lines. Each roof is in the shape of a hexagon with the diameter of 8.6 m (and the edge of 4.3 m). It is supported by six ribs that go from the edges of the flat roof to the central hexagonal 5 m high pillar (figure 7).

3.8. Railway station canopies

The canopies at the main railway station form the largest tree-like roof structure in Ljubljana. Together there are 84 reinforced concrete roof structures that cover more than 7400 m2. They are separated in three rows, each row is more than 260 meters long and consists of 28 roofs. Each roof is designed as a HP, stands on 3.5 m high pillar, and covers a square of 9.4×9.4 m (figure 8). All edges of all roofs are of the same thickness.

Figure 6. Photo of canopies for cars in Celovška street [10]

Figure 7. Photo of gas station in Dunajska street [10]

Figure 8. Photo of canopies at the railway station [10]

4. The tree-inspired structures today

Although tree-like structures do not represent the mainstream in structural development, they have been never fully abandoned since 1970's. On the contrary, one should just remember Newark Airport Terminal A in New Jersey, USA, (1973), or Stuttgart Airport Terminal in Stuttgart by Von Gerkan, Marg+Partner (1991). In addition, more than 200 Repsol gas stations designed by Norman Foster + Partners have been built all over the Spain since1996.

At the turn of the century even more tree-like structures were built using different materials: Santiago Calatrava used steel for Oriente Station in Lisbon (1998), Thomas Herzog used glue-laminated timber and steel for EXPO roof in Hanover (2000), Shigeru Ban used cardboard as the main material for Vasarely Pavillion in Aix-en-Provence (2006), Zaha Hadid used steel and tensile fabric for temporary Lilas Pavilion for Serpentine Gallery (2007) in London.

The Germen architect and structural engineer Frei Otto designed convertible roofs with umbrellas for the 1977 Pink Floyd tour. His student Mahmoud Bodo Rasch specialized in the construction of large convertible umbrellas and upgraded Otto's work. He designed convertible umbrellas in front of Al Hussein Mosque in Cairo, Egypt (2000) (16×16 m), Hotel d´Angleterre in Lausanne, Switzerland (2002), Sandy Lane Hotel in Barbados (2007), Royal Terminal in Jeddah, Saudi Arabia (2008) (29×29 m), and Prophet´s Holy Mosque in Medina, Saudi Arabia (2011), where he designed 250 convertible umbrellas (26×26 m).

5. Results and discussions

In section 3, eight tree-inspired structures built in Ljubljana during the 20th century were described as case studies. They are either mushroom or umbrella structures and the distinction between them is the main issue of this paper.

In table 1 the chronological development of umbrella and mushroom structures built in Ljubljana is presented. The Ljubljana's oldest roof supported by one pillar is Franjo Dědek's car repair canopy. Most likely all designs and descriptions of this building have been lost during the years. But because of its 8 reinforced concrete cantilevers and beams between them, the structure is more umbrella-like. The second oldest described-in-detail building is the circular Jurček Pavilion. It has a beamless reinforced-concrete ceiling construction and thus it is a direct successor of a mushroom slab construction. Because of the beams that connect the central pillar with the edges of the octagonal roof, Milan Mihelič's Hall C is an umbrella structure. This is also the case of Mihelič's gas station where the reinforced part of the roof is in the shape of a rose or, described somewhat poetically, a lace. Without ribs, the gas station by Ravnikar is clearly a mushroom structure. However, with its simple design and without any decoration

it is more profane. Each element of the six canopies at Celovška street should be considered an umbrella structure because of its four ribs that lead from the central pillar to all four edges. This is also the case in the hexagonal gas station in Dunajska street where the ribs reach all six corners of each roof structure. Each of the 84 mushroom structures that form the railway station canopies, is itself made of four hyperbolic paraboloids.

Table 1. Chronological development of tree-inspired structures in Ljubljana.

Author Name Construction time	Location	Side × Side × Height (m) Shape of the roof Number of structures	Type of the structure	Photo [10]
Franjo Dědek: car repair canopy 1933	Celovška street 38, Ljubljana	10×10×6 square 1	umbrella	
Marko Šlajmer: Jurček Pavilion 1960	Dunajska street 18, Ljubljana	r = 13.5; h = 6 circle 1	mushroom	
Milan Mihelič: Hall C 1965-67	Dunajska street 18, Ljubljana	22×22×6 octagon 4 in a line	umbrella	
Milan Mihelič: gas station 1967-68	Tivolska street 46, Ljubljana	19.2×19.2×7.1 square 1	umbrella	
Edvard Ravnikar: gas station 1968-69	Tivolska street 43, Ljubljana	19×19×5.8 square 3 in a line	mushroom	
canopies for cars 1969-70	Celovška street 42b, Ljubljana	10×10×5 square 6 in a line	umbrella	
gas station around 1970	Dunajska 70, Ljubljana	4.3×4.3×5 hexagon 6 in two lines	umbrella	
railway station canopies around 1970	Trg OF 9, Ljubljana	9.4×9.4×3.5 square 84 in 3 separate lines	mushroom	

The primary structures of all eight buildings are made completely of reinforced concrete. Only two out of eight structures have façade. In both cases a façade is made as a curtain wall: Jurček pavilion have

prefabricated fully glazed elements placed in an aluminium profile, and Hall C have glazed fronts with shads that are hung from the roof.

By using reinforced concrete, it was possible to make a roof with just one supporting pillar. The decision for using the one-pillar structure was based on the same requirement in all eight Ljubljana's structures: canopies, exhibition halls, or gas stations require as much open floor space as possible. Many of them have gutters inside each pillar. Even if the building consists of more than one pillar, each structure is separated from another and thus acts as an independent structure. This is the case of Hall C where 4 units were built, Ravnikar's gas station with 3 separate roofs, the canopies for cars at Celovška street with 6 units, the gas station in Dunajska street with 6 roofs, and the 84 canopies at Ljubljana's main railway station. The small gaps between separate roofs of the same building is very well seen in figure 7. Repetition of a greater number of identical elements is preferable as it allows prefabrication which makes construction more economical.

Mushroom and umbrella structures should be produced from prefabricated elements. But back in 1970s, the manual work in Yugoslavia become more expensive and thus the relatively closed Yugoslav market was too small for production of small quantities of quality prefabricated concrete elements that require plenty of manual scaffolding work. However, by using the same prefabricated elements again and again the architectural expression turns out poorer. This is in the case of Ljubljana's main railway station canopies where 84 identical roofs were built without any consideration for architectural splendor. On the other hand, Mihelič's gas station canopy and Hall C clearly display the architect's touch.

The two earthquakes, the first near Skopje, now in FYROM, in 1963 and the second in Furlania, Italy, in 1976, triggered the introduction of much higher safety standards for earthquake-resistant design in Yugoslavia. The weakest structural element in any tree-like structure is the pillar. And as more than 50% of the mass of a mushroom or umbrella structure resides in the upper half of the building, these structures were not considered appropriate in terms of earthquake-resistance. Hence, no significant mushroom or umbrella structure were built in Slovenia after early 1970's.

Finally, the distinction of a mushroom or an umbrella structure is in many cases mixed or imprecise. In literature and especially in the documents found on the World Wide Web, architects, art historians and laymen often describe tree-inspired structures inadequately or even incorrectly. This is evident in the case of Hall C described by Bernik in [14] or in the case of Mihelič's gas station [15]. But from the analyses of the described eight three-inspired structures, simple definitions of a mushroom and umbrella structures can be derived.

For common public a tree-like structure can be defined as a structure that resembles a tree, i.e., it consists of a foundation (root), a pillar (trunk), and a roof (branches with leaves). The definition of a mushroom structure could be made in a similar way: a mushroom structure consists of a foundation (mycelium), a pillar (stem), and a roof (cap). Likewise, an umbrella structure is defined as a structure with a foundation (handle), a pillar (shaft), and a roof (canopy), but it should also contain ribs (stretchers). All these definitions are based on how the structure looks like and thus non-experts can tell the difference between umbrella and mushroom structures based on whether the structure has ribs or cantilevers (umbrella) or not (mushroom). However, they should be careful as ribs might be hidden beneath a secondary structure.

For experts, i.e., civil engineers and hopefully architects, the difference between mushroom and umbrella structures can be defined more precisely. As the umbrella is an example of a prestressed membrane structure with locked-in stresses, the umbrella structure could be defined as a structure where the tension loaded membrane roof works together with ribs, thus the load force is transferred to the central pillar indirectly via the ribs. On the other hand, in the mushroom structure the load force in every single point of the roof is transferred directly to the central pillar. Hence, tree-inspired structures should be classified based on how the load force is transferred to the central pillar: directly (mushroom) or indirectly via ribs (umbrella).

6. Conclusions

In literature, the tree-inspired structures can be found under many different names: dendriforms, calices or lily-pads, mushrooms, hyperbolic paraboloids, hypars, HPs, or umbrellas. Nowadays the mushroom structure and the umbrella structure are the predominant terms. The distinction between mushroom and umbrella structures has not always been clear. However, the analysis of eight different tree-inspired structures in Ljubljana leads to the clarification of the definitions of the mushroom and umbrella structures: the latter have ribs or cantilevers while the former do not. Hence, art historians and laymen can spot the difference by naked eye (provided that ribs are not covered by a secondary structure) while the civil engineers and architects should find the difference in how the load force is transferred from the roof to the central pillar. In the mushroom structure, the load force in every single point of the roof is transferred directly to the central pillar while in the umbrella structure, which consists of a tension loaded roof that works together with ribs, the load force is transferred indirectly via the ribs.

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[10] all photos by Lara Slivnik
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