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Assessment of current state of Modernist building heritage of Skopje in terms of sustainability, energy efficiency and authentic appearance degradation

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Abstract. Skopje has unique examples of modernist architecture that play a major role in creating the new identity of the city, which was completely lost after the earthquake in 1963. In the last decade, awareness has been raised that modernist buildings deserve to be protected as cultural monuments. On the other hand, concerning energy efficiency and sustainability aspect, they were built without thermal insulation and thus have extremely poor thermal properties. In order to improve the energy efficiency, retrofit interventions are constantly being implemented and their authentic appearance have been changed. Many buildings have already been changed to an unrecognizable stile which threatens the overall architectural identity of the city. Therefore, systematic research has been done on 50 valuable buildings from the period of Modernism in Skopje. The buildings are selected according to their architectural, structural and cultural-historical values. They are analysed from following aspects: construction, building materials, thermal properties, function, cultural heritage protection, level of authenticity degradation, preservation and retrofit measures. The purpose of this paper is to define the most common types of buildings, which are in same time the most problematic in terms of energy efficiency, sustainability and authentic appearance.

1. Introduction

The catastrophic earthquake in 1963 caused human losses, irreversible degradation of the cultural and historical building heritage and changed the image of Skopje forever. The earthquake consequences were: over 1000 human casualties and 80% of the building stock was destroyed [1]. The buildings that were built in the post-earthquake period belong to the architectural style, known as "Modernism". This style became a main architectural characteristic of city of Skopje. Although this architecture dates from the "recent" past and often its historical values are not recognized, it is undoubtedly an important cultural and historical heritage [2].

Modernist architecture introduces a new ideology not only in the cultural and architectural sense, but also in the structural sense, especially in the use of new types of construction and building materials. Modernist buildings represent over 60% of the building stock [3], and from aspect of energy efficiency, thermal comfort and sustainability the city is facing a serious environmental issues in terms of energy consumption and emissions [4]. These buildings are large energy consumers, especially since they are built without sufficient thermal insulation or, more often, with absence of thermal insulation [5]. This situation poses the question: "How to improve the energy efficiency, sustainability and the negative environmental impact of modernist buildings, without destroying their authentic appearance?" The procedure is different for each type of building and it depends on numerous aspects, such as: type of construction, building materials especially the building envelope, protection as a cultural heritage, conservation and degradation degree etc. For this purpose, through a critical selection of 50 representative buildings, an analysis of the current state of the modernist buildings in Skopje, in relation to all the above mentioned aspects, have been made.

As a result, the most problematic types of buildings have been identified, in terms of both their thermal properties and the uniqueness of the architectural design, which will further define the type of buildings that need special attention for improving their energy efficiency and sustainability.

2. Historical context and current condition of Modernist architecture in Skopje

2.1. Categorisation of buildings according to the periods of modernization of the city

The period before World War I (1914) is the earliest period of emergence of modernist architecture in Skopje. In this period, the Traditional Balkan architecture was dominant [1]. Buildings from this period are not analyzed in this study. At the late 80's and during the 90's, a new architectural movement known as Postmodernism emerged and this style is not analyzed in this paper, too. [3] In general, the modernization period of Skopje is divided into three basic periods: I period (1914-1963) early Modernism, II period (1963-1975) mature Modernism and III period (1975-1991) late Modernism. Although the I and III periods cover longer time intervals, architectural production is significantly larger in the II period, when in a period of 15-20 years, the city experiences building expansion and modernist architecture reaches its peak. For this reason, from the I and the III period 20 buildings will be analyzed, (10 representative buildings for each of them), while from the II period 30 buildings will be analyzed.

2.2. Categorisation of buildings according to the thermal insulation materials

According to the type of materials being used and weather thermal insulation is applied or not, the buildings in Skopje are classified into four groups [5]. The first grope are buildings built before 1963, without thermal insulation (less than 10% of existing stock). The second group are buildings built after the earthquake until the end of the 70's, built in accordance with the criteria for seismically resistant construction, without thermal insulation (over 60% of existing stock). These buildings were built as skeleton reinforced concrete structures, with external walls of 20-25cm thick ceramic blocks. The construction with prefabricated reinforced concrete elements was also common in this period. Prefabricated elements, most suitable for rapid construction, as well as reinforced concrete walls casted on site, again with absence of thermal insulation, were used for most of the buildings of this group. The third group are buildings built between 1980 and 1991. These buildings were built in accordance with the first Yugoslav standards with mandatory use of thermal insulation, but insufficient and not in line with today's energy efficiency standards. The buildings built in period from 1991 up to now, belongs to the forth group. As a result of absence of regulation by law to meet energy-saving criteria, the buildings were built with, but not sufficient thermal insulation [5].

2.2.1. Thermal properties analyses of buildings by period of construction

According to the research data from [6] and [7], a comparative analysis of the U-values of the building envelopes for buildings from different periods was made. The measured values of existing old buildings built prior to the appearance of any energy efficiency standards [7], values according to Yugoslav standards [8], values measured in buildings after the adoption of energy efficiency measures (beginning of 2000) [7] and maximum prescribed values in accordance with today's Rulebook on Energy Performance of buildings [6] are summarized and presented in Table 1 and Figure 1.

Table 1 shows the U -values of the building envelope elements (exterior walls, roof, carpentry and ground floor). The mean values of the available energy audit results of individual buildings are adopted as present U-values. The standards, the methods of construction and building materials that have been used in the Republic of Macedonia in the past periods are considered, too [7].

Table 1. U-values of building envelope structural elements of old and new buildings, built in accordance with and without energy efficiency standards [6] [7] [8]

Building envelope	U-values (W/m^{2}K) of existing buildings without energy efficiency standards	U-values (W/m^{2}K) of existing buildings according to Yugoslav standards	U-values (W/m^{2}K) of buildings according to nowadays EN ISO standards	Max. prescribed U-values (W/m^{2}K) according to the ''Roolbook for Energy Efficiency of buildings''
Exterior walls	1.30	1.10	0.31	0.35
Windows	3.00	2.3 -5	1.30	1.30 -2.0
Roof	2.00	0.80	0.35	0.25
Ground floor	1.70	1	0.38	0.4

Table 1 shows the huge difference in the measured U-coefficients of old buildings, before the existence of any standards, and of new ones, according to today's standards. The U-coefficients of the exterior walls of nowadays buildings decreased by 76.15%, for the windows by 56.67%, for the roof construction by 82.5% and for the ground floor by 77.65%. From Table 1 and Figure 1 it can also be seen that the values given in the first Yugoslav standards, according to [8], do not differ greatly from the measured values of the existing old buildings, which means that during the 70's enough attention to the energy efficiency was not paid. In the Rulebooks of 70's, for the first time the calculation of thermal characteristics became a compulsory part of the project documentation, but they were calculated according to the one dimensional heat transfer methodology. During the 80's, the energy efficiency regulations became stricter, meaning that the U-coefficients for walls and roofs were corrected. According to those values (for example, the coefficients were reduced from 0.93 to 0.70), the constructors were highly encouraged to implement thicker thermal insulation for the building envelope. Those calculations were also based on the linear calculation methodology. In 1987, new calculation rules using the methodology of total energy losses were adopted and they are still in use.

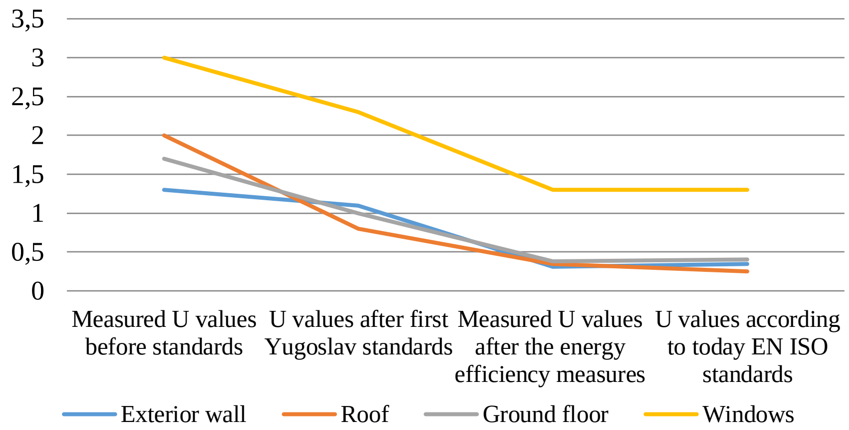

Figure 1. Comparison of U-values of buildings from different periods

According to the above presented data, it can be concluded that buildings from the II period, as most present in the building stock, are of great architectural and cultural importance and in same time are problematic from the aspect of energy efficiency. Figure 1 shows the decrease of U-values of the building elements, as a result of involvement of stricter energy efficiency criteria. The same can be concluded from Table 1. The maximum allowed U-values of the building elements constructed after the first energy efficiency measures were involved, are even greater than the measured U-values obtained by energy audit, indicating that in Macedonia, in the late 90's, the construction of energy efficient buildings begun. However, this percentage is very small, only 6% of the total building stock [7].

3. Research methods

The research of the selected buildings has been conducted through several methodological procedures:

- Collecting and documenting data, which includes: Insight into the buildings' project documentation; "In situ" visits and photo documentation of all analyzed buildings; Use of written and graphic sources from existing literature (books, papers, dissertations and data from the Internet); Interview with architects - authors of analyzed buildings.
- Analyzing the collected data, which includes: identifying the structural, architectural, thermal and cultural-historical properties of the buildings; Categorization of buildings according to their: type of construction, building materials, cultural heritage protection, shape, volume, degradation, preservation, year of construction; Selecting data in tables, where the most important specifics for each building are explained in detail.
- Selection of "most problematic" buildings which includes: Summary of final data of different types of buildings according to the analysis of their architectural, structural and thermal characteristics; Defining the key problems arising from the analysis; Identification of the most prevalent typologies; Detecting the most problematic buildings.

The buildings are selected according to the following values: architectural value which implies that the objects are valuable representative of a certain Modernist style, possess unique architectural design and aesthetics, are designed by a significant author; structural value - buildings are constructed in different structural systems, specific to the building materials and construction techniques; cultural and historical value - the buildings play an important role in shaping the identity, history and culture of the city. The researched buildings, chronologically arranged, are shown in Table 2.

4. Research results

The results of the conducted analysis of modernist buildings in Skopje, through the three periods of modernization of the city, are summarized, discussed and explained in this part.

4.1. Timeline of construction and building's functions

The intensity of the construction over the years and the participation of the different functions of the analysed buildings are shown Figure 2.

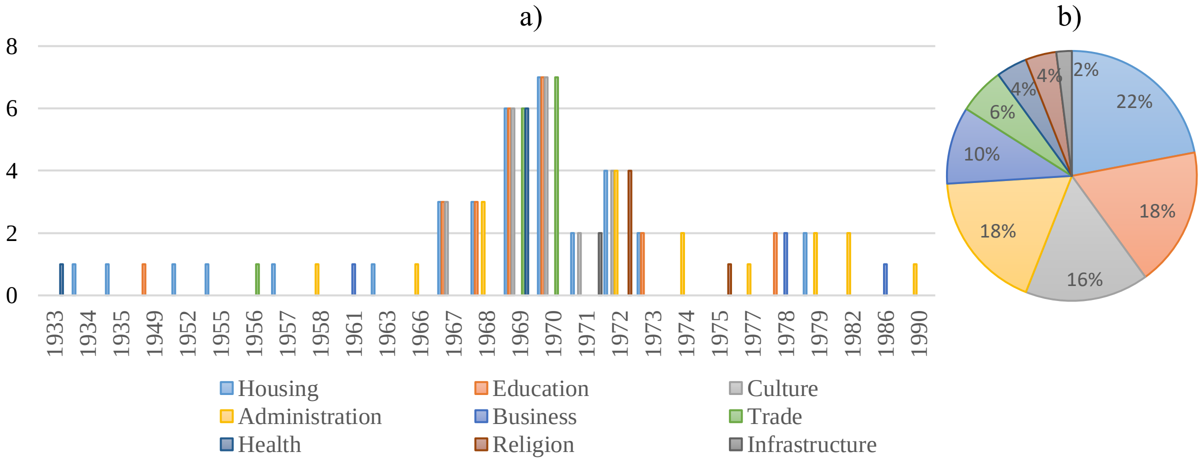

Figure 2. a) Period of construction and function b) Percentage of representation of different functions

From this analysis it can be concluded that the intensity of construction is highest after the earthquake, especially in the years following the adoption of the new urban plan for reconstruction of the city, (1966-1975) which is defined as "period II" of Modernism. From Figure 2-a it can be seen that during this period most of the residential buildings and most important public institutions, such as public administration, educational, cultural commercial, health, and infrastructural buildings, were built.

Table 2. List of the selected representatives of the Modernism of the City of Skopje**.**

	Name of the building	Architects	Period	Function
1	Surgery Clinic "St. Naum Ohridski "	Drago Ibler, Drago Galic	1933-1934	Health
2	Residential building "Zeleznicka kolonija"	Mihail Dvornikov	1934-1946	Housing
3	Residential building "Dom Ibni Pajko"	Gligorije Tomik	1935-1938	Housing
4	Faculty of natural and mathematical sciences	Edvard Ravnikar	1949-1965	Education
5	A set of five residential towers	Aleksandar Serafimovski	1952-1959	Housing
6	Grand hotel (Holiday Inn)	Slavko Levi	1955-1964	Housing
7	Department store "Nama"	Slavko Brezovski	1056-1959	Trade
8	Student dormitory "Kuzamn Jofovski Pitu"	Jovan Rankovik, B. Micevski	1957-1958	Housing
9	Workers' Home "Koco Racin"	Slavko Brezovski	1958	Administration
10	Electro Macedonia Building (Ohis, ESM)	Branko Petricik	1961-1962	Administration
11	"Russian" residential buildings "Karposh"	State Committee of Construction of USS	1963-1965	Housing
12	Historical Archive of the City of Skopje	Georgi Konstantinovski	1966-1968	Administration
13	Primary School Johannes Heinrich Pestalozz	Alfred Rod	1967-1969	Education
14	National library,,St. Clement of Ohrid"	Petar Mulickovski	1967-1972	Culture
15	"City Wall" residential buildings	Bogacev,Simoski,Serafimovski, Kjoseva	1967-1976	Housing
16	Government of R.Macedonia	Petar Mulickovski	1968-1970	Administration
17	High School "Nikola Karev"	Janko Konstantinov	1968-1970	Education
18	Residential buildings "Block B1-B7"	Trifun Janev	1968	Housing
19	Museum of Contemporary Art	Klisevski, Mokshinjski, Vjanbicki	1969-1970	Culture
20	Military Hospital (today "City hospital")	Josip Osojnik, Slobodan Nikolik	1969-1971	Health
21	High School "Orce Nikolov"	N. Bogacev, A. Smilevski	1969-1971	Education
22	Medical School "Pance Karagjozov"	Janko Konstantinov	1969-1973	Education
23	Student dormitory "Goce Delchev"	Georgi Konstantinovski	1969-1977	Housing
24	City Shopping Center (GTC)	Zivko Popovski	1969-1973	Trade
25	High School "Josip Broz Tito"	V. Ladinska, S.Gjurik, Z.Gelevski	1970-1971	Education
26	Natural Science Museum	Trajko Dimitrov	1970	Culture
27	Skopje Fair	Micevski,.Gurik, Dimitrov, Gelevski	1970-1972	Trade
28	City Library "The Miladinov brothers"	Prohirija Hadzikostova Pesik	1970-1973	Culture
29	Theater of Nationalities	Vera Kjoseva, Ljubinka Malenkova	1970-1974	Culture
30	University Campus "Ss.Cyril and Methodius	Marko Musik	1970-1974	Education
31	Museum of Macedonia	Mimoza Tomik, Kiril Muratovski	1971-1976	Culture
32	Transport Center	Kenzo Tange	1971-1981	Transport
33	Hotel Continental	Zivko Gelevski, Dimitar Dimitrov	1972	Housing
34	National Hydrometeorological Institute	Krsto Todorovski	1972-1975	Administration
35	Youth Cultural Center "May 25th"	V. Mackik, R.Vlcevski, D.Vanov	1970-1973	Culture
36	National Bank of the R.Macedonia	Olga Papesh, Radomir Lalovik	1974	Administration
37	Telecommunication Center and Counter Hall	Janko Konstantinov	1979-1981	Administration
38	Macedonian National Theater (today MOB)	Kacin, Princes, Spindler, Urshik	1972-1980	Culture
39	Church of St. Clement of Ohrid	Slavko Brezovski	1972	Religion
40	Macedonian Academy of Sciences and Arts	Boris Cipan	1973-1976	Housing
41	Radio Television Skopje (MRTV)	Haralampi Josifovski, Nako Manov	1974-**1983**	Administration
42	Cathedral of the Sacred Heart of Jesus	Blagoja Micevski, Slavko Gurik	1975-**1982**	Religion
43	Business Building "ZOIL Macedonia"	Kiril Muratovski, Miroslav Sidovski	1977-1980	Business
44	Institute of Earthquake & Seismology	Georgi Konstantinovski	1978-1980	Housing
45	Office building "Vardar Import - Export"	Dimitar Dimitrov, Roza Minceva	1978-1980	Business
46	Residential Towers Karposh IV	Aleksandar Smilevski	1979-1981	Housing
47	Ministry of Education and Science of R. M.	Blagoja Kolev	1982	Administration
48	Macedonia Tabak Business Building	Slave Vrencinovski	1982	Business
49	Paloma Bianca Building	Trajko Dimitrov	1986	Business
50	Ensemble of Judiciary and Municipal Court	Nako Manov, Dionis Andonov	1990	Administration

In the period before the earthquake, 1933-1963 (period I) the construction of residential buildings was dominant, while, during 1975-1990 (period III) the commercial and administrative buildings were predominant. That means that the most productive construction period in Skopje is denoted by buildings built from the mid 60's to the late 70's. Figure 2-b shows the participation of the specific functions of the buildings. The highest percentage is of the residential buildings (22%), followed by educational buildings (18%) and public administration (18%), cultural buildings (16%) business (10%), commercial (6%), health (4%), religious (4%) and infrastructure i.e. transport (2%).

4.2. Types of building's structural systems

The structural systems of the investigated buildings are grouped into eight types: type 1. Massive reinforced concrete structural system; type 2. Skeleton reinforced concrete structural system; type 3. Prefabricated reinforced concrete structural system; type 4. Combined (skeleton-massive) reinforced concrete systems; type 5. Steel skeleton structural system; type 6. Hanging construction (steel and concrete); type 7. Shell structural system and type 8. Prestressed concrete structural system. (Figure 3-a,b)

Despite the fact that the period before 1963 is recognizable by masonry structures, the researched modernist buildings from this period (I period) were built as skeleton reinforced concrete structures. This structural system was dominant in periods II and III too (Figure 4-a), so 56% of all analyzed buildings belongs to this system (Figure 4-b). Massive reinforced concrete structures, as a trend of building, was most commonly used in 'brutalist' architecture (60's and 70's). This type of buildings is characteristic for the period II and represents 8% of the total number of researched buildings.

In 1963 Skopje was destroyed and there was a need for intensive construction of dwellings [2]. This need resulted in construction of prefabricated structures of reinforced concrete elements, especially for constructing residential buildings and schools. The analyzed buildings of this type participate with 6%. Most of the buildings were constructed in combined reinforced concrete skeleton-massive system, especially buildings with large open areas such as public institutions, cultural and educational buildings and they had expansion in period II, again mostly in the "brutalist" architectural style, with participation of 20%. The use of steel skeleton construction began in period II. The analyzed buildings participate with 2%. Steel structures, as frames and trusses, in combination with RC elements, were used for overcomming large spans. The presteressed concrete structures appeared during period II. The analyzed buildings of this type participate with 2%. 4% are shell structures and this type is characteristic for religious buildings mostly built in period II and III.

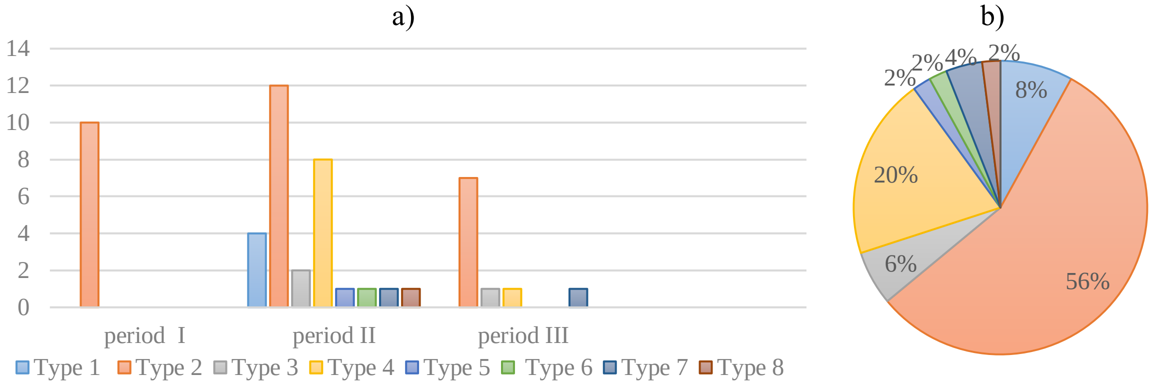

Figure 3. Types of structural systems a) by construction period b) by participation

4.3. Building materials used in the building envelope and their thermal properties

Most of existing buildings are 30 to 40 years old and do not have thermal insulation. It is estimated that only 6% of buildings in the country have energy class "C" or "D", while the rest are energy class "E", "F" or "G". Over 90% of buildings have no thermal insulation on the exterior walls, roofs and ground floors. [7] The exterior walls are the most important part of the building envelope and have the largest participation in the total heat loss. With proper insulation of the envelope the heating costs can be reduced by 80-90% [10]. For defining proper calculations on energy consumption and for implementing adequate measures for improving the energy performance of existing buildings, the structures of the building envelopes were analyzed. As a result, the exterior walls of the existing buildings are grouped into 10 types: type 1. Masonry wall of ceramic blocks or bricks with façade finishing render; type 2. No- finish concrete walls, known as *"beton brut"* [10] with specific "in situ" made façade design; type 3. Masonry or concrete walls with stone or ceramic facade elements, combined with large glass surfaces; type 4. Curtain wall panels with steel substructure or sandwich panels with insulation usually combined with structural glass; type 5. Combined concrete walls and façade brick masonry visible on facade without finishing layer; type 6. Combined no-finish concrete walls and masonry (ceramic blocks) with stone, ceramic or other finishing layers; type 7. Concrete walls with finishing facade plaster or only protective color coating; type 8. External thermal insulation composite systems (ETICS) – masonry walls with thermal insulation of expanded polystyrene on cement mortar with facade finishing render; type 9. Masonry ceramic block walls with finish of ceramic or aluminum panels on steel substructure with stone or glass wool insulation; type 10. Masonry ceramic block walls with polyurethane or expanded polystyrene thermal panels on steel substructure and decorative façade finishing render.

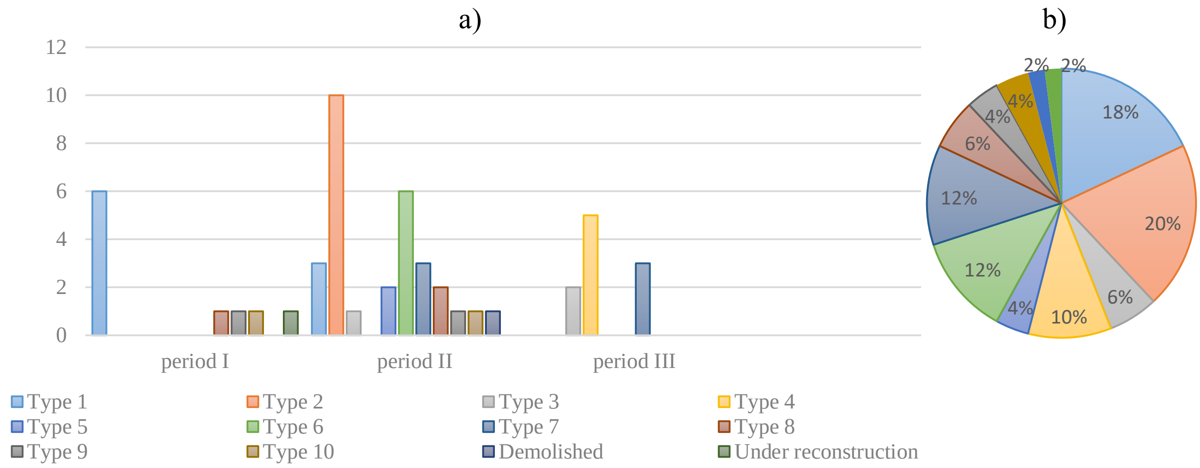

Figure 4. Types of exterior walls, made of different building materials a) by construction period b) by participation

Figure 4 shows that the buildings with exterior walls made of concrete with no finish layers, known as "*beton brut*" i.e. type 2, have the largest participation of 20%. These buildings are the most problematic from many aspects, particularly their extremely low thermal properties and exposure of unprotected concrete to atmospheric influences, which leads to carbonization of the concrete. Next, with a participation of 18% are the buildings whit exterior walls made of masonry and finished with facade render i.e. type 1. With the same participation of 12% are the buildings made with exterior walls type 6 and type 7. Buildings with type 4 exterior walls have 10% participation. 6% are represented by buildings made of type 8 exterior walls. Buildings with external thermal insulation as composite systems, or type 3, have 6% participation, and these buildings are mostly refurbished by additional layers of thermal insulation. With the same participation of 4% are the type 9 and type 10 exterior walls. The remaining 4% belong to buildings whose facades are currently under reconstruction, or have been demolished.

Based on the projects documentation and in situ visits of the buildings, it is found out that the carpentry dates from the construction period and is usually made of wooden frames of different quality with single glazed or double-glazed windows. The heat loss through the windows accounts for up to 50% of the total heat loss through the envelope. [11] 24% of the analyzed buildings have a complete change of carpentry (from wooden or aluminum framed and single-glazed windows to PVC framed and double-glazed windows). 26% of carpentry has been partially changed, mostly in residential buildings by tenants. The remaining 50% of the buildings have inadequate carpentry in accordance with today's energy efficiency regulations. In the total heat loss of a building, the roof accounts for up to 10-30% [11]. Most of the exanimated modernist buildings have flat roofs with or without insulation. Flat roofs are problematic not only because of the difficulties with the drainage of the rain water, but also because of the principles of installing the thermal and hydro insulation. 28% of the buildings have reconstructed roofs with improved thermal properties. The remaining 72% of the buildings are without or insufficient thermal insulation. Heat loss through the ground floor is about 6-10% [9]. Interventions for additional thermal insulation of existing floors have rarely been implemented.

4.4. Renovation and conservation measures, improvement of thermal characteristics of buildings
According to the conducted research it has been concluded that most of the various renovation interventions that have already been made, are inappropriate and changed the buildings authentic appearance. The interventions are categorized into four types, based on two important aspects such as the level of the intervention (smaller or larger interventions) and the degree of improvement of the building thermal properties, as follows: type 1. Buildings in original (authentic) condition with very low thermal properties (without thermal insulation materials); type 2. Buildings with minor interventions (interior renovation, partially carpentry changed, roof repair) with slight improvement in thermal properties; type 3. Buildings with major interventions (facade renovation, which means adding thermal insulation, reconstruction of the structural elements) with significant improvement of thermal characteristics; type 4. Buildings with major interventions (refurbishment and reconstruction) but without improvement of thermal properties, i.e. without adding thermal insulation.

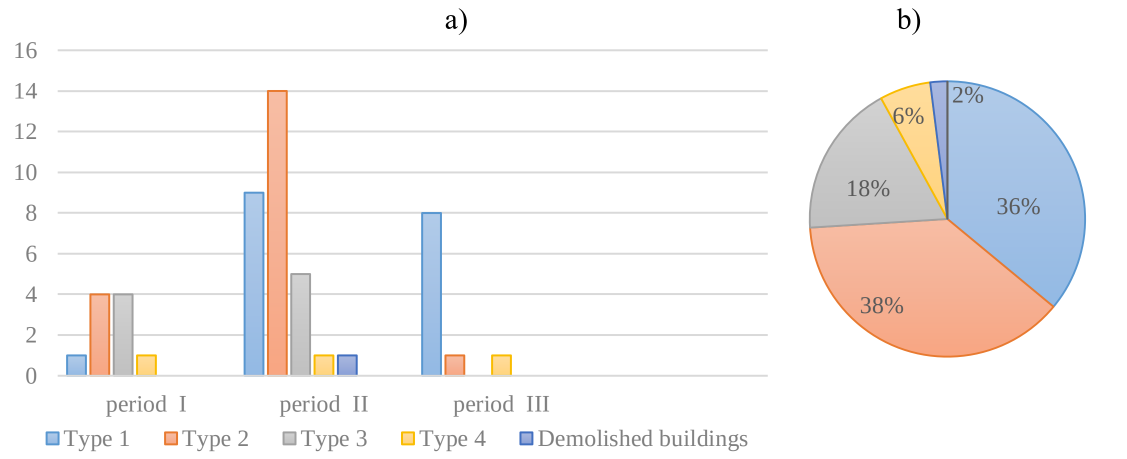

Figure 5. Types of implemented interventions: a) by construction period b) by participation

The results (Figure 5-a and 5-b) show that buildings with minimal interventions have the largest participation, especially in carpentry change, with 38% of the total number of buildings. Partial replacement of the carpentry or just the roof reconstruction, insufficiently improves the energy efficiency if the walls remain without insulation. With a participation of 36% are the buildings that are in their original state, and do nothing. These buildings have extremely low thermal properties but they also have a high degree of degradation. Buildings with major interventions i.e. complete refurbished (with new thermal façade, roof insulation and completely changed carpentry) are 18%, and there is a significant improvement of their thermal properties. However, there are also buildings that have been renovated but do not have energy efficiency improvements, since no thermal insulation materials have been used in the process of renovation. This is often a case where, due to the preservation of authenticity, energy efficiency is neglected. These buildings have a participation of 6%. From the analysis it can be concluded that 80% of the buildings have very low thermal properties, not corresponding to nowadays standards.

4.5. Repercussions of implemented renovation measures on the originality of the buildings
When implementing renovation measures to cultural heritage buildings, it is always difficult to maximally respect the original appearance of the building [4][12]. Improving the sustainability and

energy efficiency of cultural heritage buildings is a complex process, which is even more complicated for buildings that are in daily function. It is no longer a question of energy efficiency of the future, but of historical cultural heritage architecture. The solution is often compromise between authenticity and better energy performance [12]. For this purpose, numerous analyses have been made on the impact of the above-mentioned renovation procedures (Figure 5) on the original appearance of buildings.

The analyses results are shown in Figure 6, where the buildings conditions with or without any interventions are divided into 7 types as follows: type 1. Unchanged authenticity; type 2. Partially impaired authenticity; type 3. Endangered authentic appearance; type 4. Imitation of authentic appearance; type 5. Complete changed authentic appearance to an unrecognizable outlook; type 6. Retained authenticity through restoration with identical materials; type 7. Important cultural monuments demolished. Figure 6-b shows that 46% of the objects are in original condition with not changed authentic appearance. This is due to the fact that in most of them, no interventions or minimal interventions such as roof repairs or interior renovations have been implemented, which often do not violate the authenticity of the overall appearance. 31% of the buildings are with partially impaired authentic appearance, which is often due to minor facade interventions such as inadequate carpentry change. 13% are buildings with endangered authenticity, which means changing the facade inappropriately, with materials and building techniques different from the original, but the architectural aesthetics and overall look are still retained. Changes are minimal: the facade material or color of the facade, the size due to the addition of thermal insulation. Imitation of authentic appearance means to compromise: preserving the appearance, while improving the building's performance with new materials. Only 2% of the analyzed buildings have implemented such a measure. In 4%, inappropriate interventions have completely changed the outlook of the buildings to unrecognizable outlook, which means change of the: material, color, design, aesthetics, style, proportions, area, i.e. overall architectural expression.

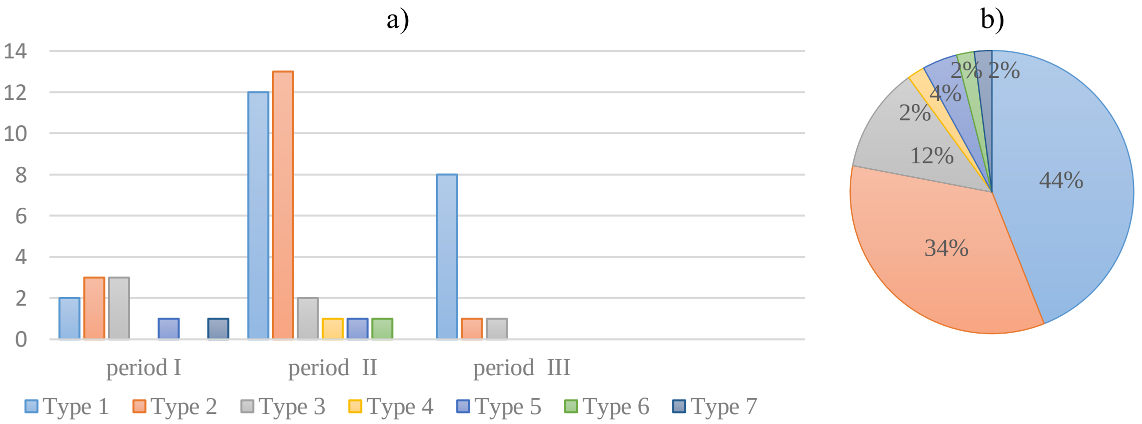

Figure 6. Authentic appearance condition: a) by period b) by participation

4.6. Protection of the buildings as a cultural heritage

Based on the data from National Conservation Institution [13], some of the modernist buildings in Skopje that were not previously considered as cultural heritage have been recognized and proposed for being treated under a certain protection regime. According to [13], from 127 heritage buildings 31% belong to Modernism, confirming the importance of modernist architecture for the city's cultural identity. For 14% of the analyzed buildings the proposed regime of protection is grade I (cultural heritage of a significant importance), 34% - grade II (important cultural heritage), while 2% are proposed to be a monumental area, Figure 7-a and 7-b. Despite the values of all analyzed buildings, 50% of them are still not recognized and protected as cultural heritage.

a) b)

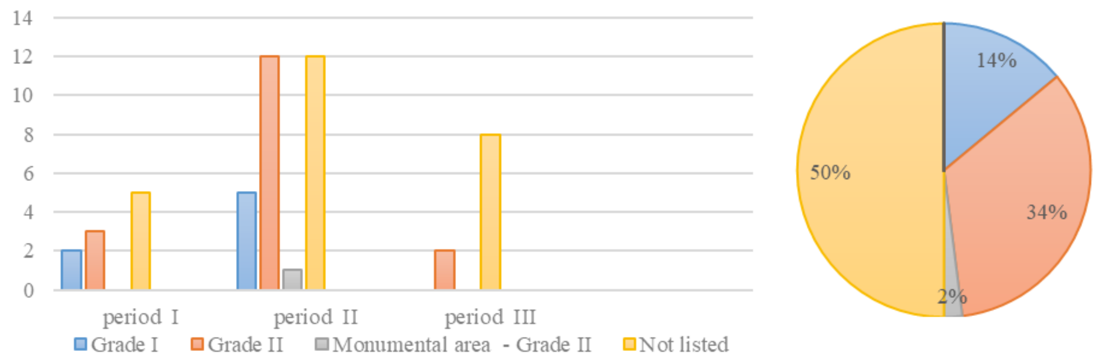

Figure 7. Protection degree of the buildings as a cultural heritage a) by period b) by participation

4.7. Detecting the key problems arising from the analyzed buildings

According to the research results, it could be concluded that the analyzed buildings face two most important, are in the same time contradictory key problems:

- the need of improvement the extremely low energy efficiency (sustainability, thermal properties, thermal comfort, energy consumption, emissions);
- the need of preservation the authentic appearance (architectural identity, originality) while protecting them from degradation (daily activities, atmospheric influences, aging).

To properly address the first problem (energy efficiency improvement), especially in terms of the thermal properties (exterior wall structure, building materials, use of thermal insulation, carpentry, etc.), but also in terms of defining the level of interventions implemented to improve the energy efficiency, all selected buildings were analyzed.

The obtained results have shown that, according to the two above-mentioned problems, the most problematic are the so called "brutalist buildings". The walls of these buildings are made of natural concrete, without external protection, completely exposed to atmospheric influences (wall type 2). Many of them have a specific facade design such as fluting, made during the "in situ" process of casting concrete in specially designed wooden moldings, where the mold marks are visible on the façade. These characteristics define the identity of modernist style known as "Brutalism" [4] [10]. These buildings, with 20%, have the largest participation of all analyzed examples (Figure 8). Most of them are the most representative monuments of Skopje's Modernism, especially public and educational institutions.

Nowadays, massive structures are still constructed and the external walls are usually made of ceramic blocks or bricks, with various finishes like: different kinds of mortars, renders, plasters, stone, ceramic, aluminum facade materials etc., which can easily be replaced. For the buildings made only of concrete, application of thermal insulation to the facade walls, while retaining the original appearance of the concrete facade, is a greater challenge and has to be investigated in future.

For each of the types of exterior walls (except for concrete walls-type 2) a number of measures for improving their thermal properties with minimal impact on the original architectural appearance have been proposed. On the other hand, problems with the "brutalist" buildings, as: energy efficiency, thermal comfort, sustainability and degree of degradation, open a new and insufficiently investigated area. This paper identifies and elaborates the key problems these buildings are faced with. The aim is to answer the question why these prevalent buildings are considerate as "the most problematic" according to all researched aspects, such as: high thermal conductivity λ[W/(Km)], high thermal mass of the concrete walls, large exposure and no protection from environmental influences, losing authenticity by isolating the envelope, disadvantages of insulating buildings from the inside, specific architectural facade design.

Based on the results from this research, the brutalist buildings are selected as most problematic buildings. Their current thermal properties and the renovation measures that will not cause change of the physical appearance will be further investigated as part of a very detailed research.

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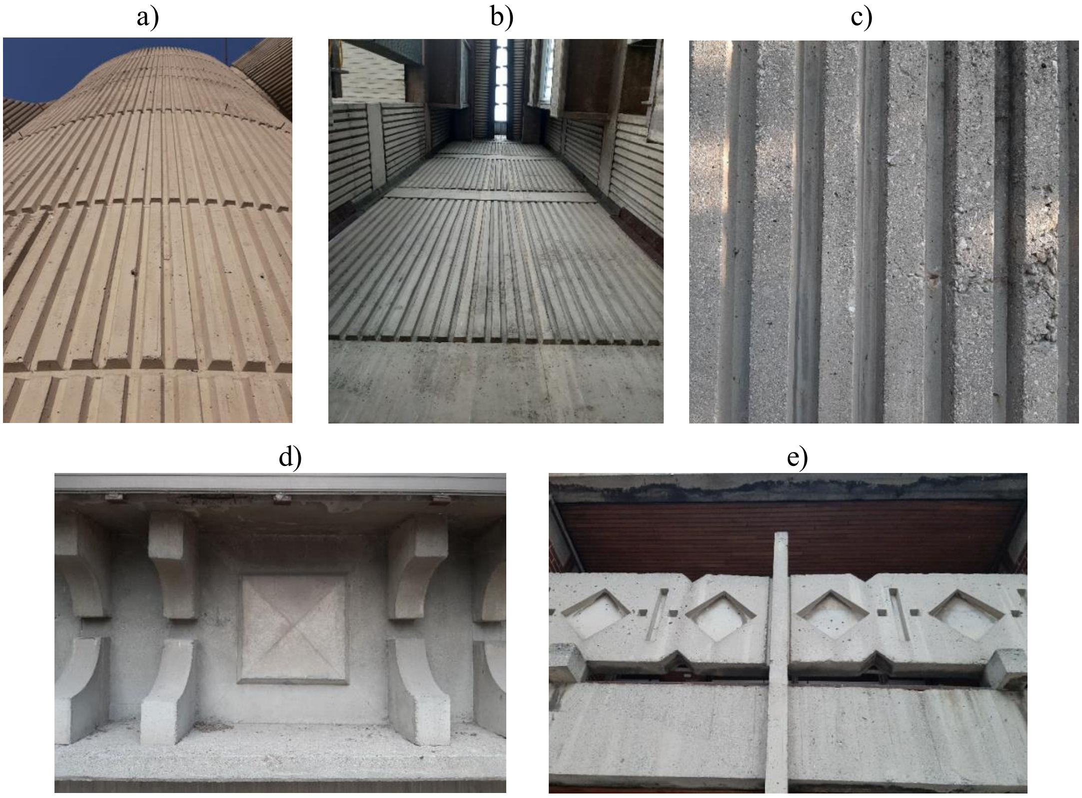

Figure 8. Buildings in Skopje that belong to modernist style known as "Brutalism"

5. Discussion and conclusion

Based on the conducted analysis, it can be concluded that the modernist buildings in Skopje represent a significant architectural and cultural heritage, both in quantity and in architectural quality as well as diversity, building materials and building innovation techniques, whose particular culmination are the buildings built in the second period of Modernism in Skopje (1963-1975). In terms of function, the three most dominantly used are: housing (22%), education (18%), public administration (18%). In terms of their construction, the main building material is reinforced concrete. Most of the buildings are built in the skeleton reinforced concrete structural system (56%), combined skeleton-massive systems (20%) and massive reinforced concrete systems (8%). According to the type of exterior wall types, the largest participation (20%) have the buildings whose envelope is entirely made of natural concrete, without finishing, molded in molds of a specific design, known as "brutalist" buildings. They are the most problematic in terms of sustainability, environment, energy efficiency and are susceptible to high carbonization of concrete. Given the fact that the first Yugoslav standards were implemented in the late 80's, and that construction expansion took place between 1963 and the late 80's, it can be concluded that within 30 years, during the period of highest construction production, buildings were built without thermal insulation. The carpentry in 50% of the buildings dates from this construction period and is usually made of single-glazed wooden framed windows. 24% of the buildings have completely changed carpentry with improved thermal performance, while 26% have only partially changed carpentry. In 28% thermal insulation to the roof structure has been added. Only 17% of the buildings have significantly improved the energy efficiency of the whole building envelope. With highest participation of 38% are the buildings with minimal and partial interventions (carpentry change, roof repair etc.). Using additional thermal insulation, replacing the carpentry with new one made of inappropriate materials, and conducting other interventions that significantly impair the originality of the buildings, have been identified as key problems in the process of improving energy efficiency and sustainability of buildings. The problems connected with the most important modernist buildings in Skopje are detected and documented in this paper. It has been found that "brutalist" buildings are the most problematic according to all of the researched aspects: energy efficiency, sustainability, environmental impact, degree of degradation, uniqueness in architectural aesthetics that cannot be compromised, cultural-historical, architectural and structural value. The further research aims to find a solution for the sustainability, energy efficiency and environmental issues of these buildings, without compromising their appearance. The research will be conducted on several types of nano-materials [12] that could be applied to the building envelope of three types of "case study" buildings. The buildings should be representative examples of brutalist architectural monuments selected according to their different function, location, orientation, construction, form, building materials and specific façade design. The future research goals are to find the best possible solution by designing several scenarios with different materials used on different buildings using software simulation for energy modeling in the buildings.

References

[1] Ivanovska Deskova A 2015 *Post Earthquake Skopje Architecture - Values and Condition in Contemporary Context - Doctoral Dissertation* (Skopje: Faculty of Architecture, Ss. Cyril and Methodius University in Skopje) p 185
[2] Lozanovska M and Martek I 2019 Skopje Resurgent: the international confusions of post-earthquake planning 1963–1967 *Planning Perspectives* **34-3** p 497-513
[3] Tokoarev M 2013 50 years of reconstruction and building of Skopje (1963-2013), historical and critical view of architecture *Porta 3* **213** p 34-45
[4] Lembo F 2014 Transforming a brutalist monument into an energy efficient building without destroying the formal appealing: the example of the Mediterranean Bank in Potenza *International Congress on Energy Efficiency and Energy Related Materials* (Springer Proceedings in Physics) **155** p 83–90
[5] Nikolovski P 2014 Overview of typical measures for energy efficiency buildings improvement, *(*Skopje, CEPRPOSARD) p 30
[6] Ministry of economy of the Republic of Macedonia 2016 Rulebook on Energy Performance of Buildings
[7] Blazev D and Fellow R Terwilliger 2017 Market Analysis of Residential Energy Efficiency in Collective Residential Buildings in the Republic of Macedonia http://habitat.org.mk
[8] Rulebook on Technical Measures and Conditions for Heat Protection of Buildings, Law on Technical Measures *Official Gazette of SFRY No. 12/65 and 55/69*
[9] Vukovic C, Petrovska S, Petkanovska I, Janevska S and Filiposki D 2009 Energy Efficiency of Farms and Rural Households (Skopje: CeProSARD) p 135
[10] Francesco P, Marino R and Lembo F 2016 Brutalist Architecture and Pathologies: How Design Mistakes Can Make a Building "Sick" from the Beginning *Case Studies of Building Pathology in Cultural Herita*ge (Singapore: Springer) p 11
[11] Lazarevska M and Trombeva-Gavriloska A 2014 Thermal insulation materials (Skopje: Faculty of Architecture, Ss. Cyril and Methodius University in Skopje) p 164
[12] M. Ganobjak et al. 2019 Aerogel materials for heritage buildings: Materials, properties and case studies *Journal of Cultural Heritage* (https://doi.org/10.1016/j.culher.2019.09.007)
[13] National institution Conservation center of Skopje 2012 Conservation project for cultural heritage for the General Urban Plan of the City of Skopje 2012-2020 (Skopje: NCCS) p 218